EFFECTS OF DIFFERENT BATTER FORMULATIONS ON QUALITY OF DEEP-FAT FRIED CHICKEN NUGGETS

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SEYHAN FİRDEVS DOĞAN

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Prof. Dr. Canan Özgen
Director

I certify this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Levent Bayındırlı
Head of Department

This is to certify that we have read this thesis and that in our department it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Gülüm Şumnu
Co-Supervisor

Assoc. Prof. Dr. Serpil Şahin
Supervisor

Examining Committee Members

Prof. Dr. Alev Bayındırlı	(METU, FdE)	
Prof. Dr. Mehmet Mutlu	(HU, FdE)	
Assoc. Prof. Dr. Serpil Şahin	(METU, FdE)	
Assoc. Prof. Gülüm Şumnu	(METU, FdE)	
Assist. Prof. Dr. Hami Alpas	(METU, FdE)	

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ABSTRACT

EFFECTS OF DIFFERENT BATTER FORMULATIONS ON QUALITY OF DEEP-FAT FRIED CHICKEN NUGGETS

Doğan, Seyhan Firdevs
M.Sc., Department of Food Engineering
Supervisor: Assoc. Prof. Dr. Serpil Şahin
Co-Supervisor: Assoc. Prof. Dr. Gülüm Şumnu

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The main objective of this study was to evaluate the effects of different flour and protein types on quality of deep-fat fried chicken nuggets. Additionally, the rheological properties of batters were studied and the batter viscosity was correlated with fried product quality.

In the first part of the study, the effects of soy and rice flour (5%) addition to the batter formulation on product quality were studied. Coating pick-up of batters, and moisture content, oil content, texture, color, volume, porosity, and cooking yield of nuggets were determined for 3, 6, 9 and 12 minutes of frying times at 180ºC. In the second part of the study, the effects of protein types (soy protein isolate, whey protein isolate and egg albumen) at different concentrations (1 and 3%) on quality attributes were studied. A batter formulation with no flour or protein addition was used as control.

In both parts of the study, flow behavior of batters prepared using different flour and protein types were determined. Soy flour and soy protein isolate (SPI) provided the highest apparent viscosity. Batter viscosity was found to be correlated with coating pick-up. All batters were found to show thixotropic behavior. The batters were modeled as power-law fluid and all of them turned out to be shear-thinning except egg albumen added batter, which was shear-thickening.

As a result of the study, among the flour and protein types used, 3% whey protein isolate (WPI) was found to be the most effective ingredient on improving quality parameters of deep-fat fried chicken nuggets. 3% WPI added batters provided the hardest and crunchiest product with the darkest color. It also reduced the oil content of fried nuggets significantly. However, low cooking yield values were observed for batters with 3% WPI. On the other hand, soy flour containing batters provided high cooking yield. Therefore, if high cooking yield with low oil content is desired, soy flour can be advised to be used in batter formulations for chicken nuggets.

Keywords: Batter, Chicken nuggets, Flour, Frying, Physical properties, Protein.

ÖZ

DEĞİŞİK KAPLAMA FORMÜLASYONLARININ KIZARTILMIŞ TAVUK PARÇALARININ KALİTESİ ÜZERİNE ETKİSİ

Doğan, Seyhan Firdevs
Yüksek Lisans, Gıda Mühendisliği
Tez Yöneticisi: Doç. Dr. Serpil Şahin
Yardımcı Tez Yöneticisi: Doç. Dr. Gülüm Şumnu

Haziran 2004, 113 sayfa

Bu çalışmanın temel amacı, değişik un ve protein çeşitlerinin kızartılmış tavuk parçalarının kalitesi üzerine etkisinin değerlendirilmesidir. Ayrıca, kaplama hamurlarının reolojik özellikleri çalışılmış ve kaplama hamurunun akmazlığı ile kızartılmış ürün kalitesi arasındaki ilişki değerlendirilmiştir.

İlk bölümde, soya unu ve pirinç unu (%5) eklenmiş hamur formülasyonunun ürün kalitesine etkisi çalışılmıştır. Kaplama hamurunun tutulması ile 180ºC'de 3, 6, 9 ve 12 dakika boyunca kızartılan tavuk parçalarının nem miktarı, yağ miktarı, yapısı, rengi, hacmi, gözenekliliği ve pişirme verimi belirlenmiştir. İkinci kısımda, değişik konsantrasyonlardaki (%1 ve 3) farklı protein çeşitlerinin (soya proteini izolesi, peynir altı suyu izolesi, yumurta albumeni) kalite niteliklerine olan etkileri çalışılmıştır. Un ya da protein eklenmemiş kaplama formülasyonu kontrol olarak kullanılmıştır.

Çalışmanın her iki kısmında da kaplama hamurunun akış davranış özellikleri belirlenmiştir. Soya unu ve soya proteini izolesi en yüksek görünür özlülüğü sağlamıştır. Kaplama hamuru akmazlığının, kaplama tutulma özelliğiyle ilişkili olduğu bulunmuştur. Bütün kaplama hamurlarının tikzotropik davranışa sahip olduğu belirlenmiştir. Bütün kaplama hamurları üstlü-yasa akışkanı olarak modellenmiş ve yumurta albumeni eklenmiş kaplama hamurunun dışında, tüm kaplama hamurlarının yapay plastik olduğu görülmüştür.

Çalışmanın sonucunda, kullanılan değişik un ve protein çeşitleri arasında, %3 peynir altı suyu izolesinin, kızartılmış tavuk parçalarının kalitesini geliştirmede en etkili ingredien olduğu bulunmuştur. %3 peynir altı suyu izolesi eklenmiş kaplama hamuru en koyu renkli, en sert ve en çıtır ürünü vermiştir. Ayrıca, kızarmış tavukların yağ miktarını önemli ölçüde azaltmıştır. Diğer taraftan, %3 peynir altı suyu izolesi içeren kaplama hamurlarının pişirme verimi düşüktür. Soya unu içeren kaplama hamurları ise yüksek pişirme verimi sağlamıştır. Bu nedenle düşük yağ içeriği ile birlikte yüksek pişirme verimi isteniyorsa, tavuk parçalarını kaplamak için kullanılacak hamurda soya ununun kullanılması önerilebilir.

Anahtar sözcükler: Fiziksel özellikler, Kaplama hamuru, Kızartma, Protein, Tavuk parçaları, Un.

To my parents

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INTRODUCTION

1.1. Deep-Fat Frying

Deep fat frying is a common and popular process often utilized in food industry due to its significant sales and vast quantity of products with distinctive flavor, aroma and crunchy texture (Saguy et al., 2003). In deep-fat frying, the food is completely immersed into hot oil. It can be defined as a process of cooking and drying through contact with hot oil involving simultaneous heat and mass transfer (Mittelman et al., 1984).

During deep-fat frying, convective heat transfer takes place from the frying oil to the surface of food and conductive heat transfer from the surface to the interior of the food. Both frying oil and water in the food are two major factors in heat transfer. Oil provides an effective medium for heat transfer toward the food, whereas water is an effective medium for heat transfer within the food. Water is a better conductor of heat than the fat, protein, and carbohydrate portions of the food (Orthoefer, 1996).

The drying behavior of a food in frying depends on its physical characteristics. Food materials are hygroscopic, capillary-porous products in which the pores are partially filled with water and partially with an air/water-vapor mixture (Moreira et. al., 1999). During the frying process, moisture either on the surface or in the interior of the food forms steam. Water on the surface of food evaporates on contact with hot oil allowing water in food to migrate outward due to the partial vapor pressure difference between the product and the frying oil. This continuous process of water flowing from interior to exterior is called as ‘‘pumping” (Lydersen, 1983). Inner moisture of the product converted to steam during frying escapes through open capillaries, pores and/or crevasses in the structure allowing oil to enter the voids left by the water, which may be important in keeping the structure from collapsing (Lozano et. al., 1989). Additionally, steam on the product surface in contact with the hot frying oil carries off thermal energy from the oil surrounding the frying food. As a result, although the temperature of the oil may be as high as 196 ˚C, product temperature is only about 100 ˚C. By this way, burning of food from hot frying oil is prevented (Blumenthal, 1991). The formation of steam during the entire cooking process is due to the greater pressure inside the food than that of the frying oil, which in turn limits penetration of frying oil through the surface to the interior of the food. Oil uptake is increased by a reduction of internal pressure due to water loss by subsequent cooling, which creates a vacuum effect (Rice and Gamble, 1989).

During deep-fat frying, some chemical and physical changes like starch gelatinization, tissue softening, in the case of raw potatoes, partial enzyme inactivation and some reactions between food components take place. A crust is formed at the product surface as a result of surface dehydration during the process, which is characterized by having very low moisture content, temperature above 100 ˚C, porous structure, and crispy texture (Moreira et. al., 1999). Together with surface dehydration of food (crust formation), absorption of oil, development of surface color, and development of flavors account for the desirable taste of fried food (Orthoefer et. al., 1996). Crust is one of the most palatable characteristics of fried foods (Varela, 1988). The development of crust affects heat and mass transfer processes, and oil uptake. It was reported that oil uptake of fried products was localized at the crust formed during deep-fat frying (Farkas et al., 1992; Gamble et al., 1987; Saguy and Pinthus, 1995). The amount of oil entering the product has been shown to be directly proportional to the amount of moisture lost and should depend on how the moisture is lost. Oil content will be low when the moisture loss is slow and continuous without the formation of large surface-damage sites (Gamble et al., 1987).

Many factors affect oil uptake including oil quality, frying temperature and duration, product shape, product composition (e.g. moisture, solids, fat, protein), and porosity, pre-frying treatments (e.g. drying, blanching) and coating (Selman and Hopkins, 1989).

1.2. Frying Batters

Batters can be defined as liquid mixtures composed of variable concentration of flour and water into which food products are dipped before frying. There exist no exact recipes for batter systems. Depending on the food substrate and the desired coating appearance, formulas can be extremely flexible to allow for maximum adaptability in product development (Loewe, 1990). Batters to coat the surface of the products are used to add value to the fried products, because coatings improve their appearance, texture, flavor, weight, and volume by reducing dehydration, aiding browning and giving a crisp texture to the fried parts (Cunningham and Suderman, 1981). In addition to restricting water and gas exchange, batters may reduce movement of cooking oils into food pieces during frying (Wills et al., 1981).

Loewe (1993) classifies batter systems into two categories: interface/adhesion and puff/tempura. The interface/adhesion batters are used with breading, serving primarily as an adhesive layer between the surface of the product and the breading; chemical leavening is not normally used. Puff/tempura batters contain leavening agents and are used as an outside coating for the food.

In puff/tempura batters, both wheat and corn flours play important roles. A typical tempura batter consists of wheat flour, corn flour and leavening agent as critical ingredients to which other flours, starches, gums, proteins, colorants and flavorings can be added as optional ingredients (Loewe, 1990). The batter uniformity and thickness together with a number of critical coating characteristics i.e. appearance, color, crispiness, adhesion or flavor determine acceptability of the finished product (Loewe, 1990). The recent trend in reducing the fat content in fried foods is leading to the development of low-fat products by using batter formulations with specific ingredients.

1.2.1. Proteins

The film-forming ability of several proteinaceous substances has been utilized in industrial applications for a long time. The food industry recognized that proteins having film-forming properties could be used for the development of edible, protective food films and coatings, provided that edibility was maintained in every step of the protein-based film or coating preparation (Gennadios et. al, 1994).

Proteins represent the most important class of functional ingredients because they possess a range of dynamic functional properties (Table 1.1). They show versatility during processing, they can form networks and structures and they provide essential amino acids, i.e. they fulfill functional and nutritional requirements. In addition, they interact with other components and improve quality attributes of foods (Kinsella et al., 1994).

Table 1.1 Functional properties of proteins in foods (Kinsella et al., 1994)

General property	Functional criteria
Organoleptic	Color, flavor, odor
Kinaesthetic	Mouthfeel, texture, smoothness, grittiness
Hydration	Solubility, wettability, water sorption, swelling, thickening, gelling, syneresis, viscosity, gelation
Surface	Emulsification, foaming, film formation
Rheological/textural	Elasticity, cohesiveness, chewiness, adhesiveness, network formation, aggregation, dough formation, texturizability, extrudability

The physical and chemical properties that govern protein functionality include size; shape; amino acid composition and sequence; net charge and distribution of charges; hydrophobicity/hydrophilicity ratio; secondary, tertiary and quaternary structures; molecular flexibility/rigidity; and ability to interact/react with other components. Since proteins possess a multitude of physical and chemical properties, it is difficult to describe the role of each of these properties with respect to a given functional property (Damodaran, 1996).

Gelation and structure-formation are important functional properties of food proteins in many fabricated and natural food products, e.g. gelatin, egg white and comminated meat products (Kinsella, 1982, 1984a,b). In each of these products, proteins contribute in varying degrees to the solid or elastic properties of the food by formation of an orderly, three-dimensional network of associated or aggregated protein molecules that are capable of physically entrapping large amounts of water within the matrix (Hermansson, 1979). The formation of a gel from protein is apparently a two-step process. The first step involves a change in conformation (usually heat-induced) or partial denaturation of the protein molecules. As denaturation proceeds, the viscosity of the dispersion increases owing to an increase in molecular dimensions of the unfolding proteins (Catsimpoulas and Meyer, 1970). This is followed by a gradual association or aggregation of the individual denaturated proteins (Ferry, 1948). During the association step, there is an exponential increase in viscosity as the material approaches a continuous network. This second step should be slow, relative to the first, so that a well-organized gel network is formed. If the second step occurs too quickly, a random network (i.e. a coagulum) that is unable to hold water is formed and syneresis occurs. A critical balance between attractive and repulsive forces must also be present for successful network formation and stabilization (Hermannson, 1979). If attractive forces predominate, a coagulum is formed and water is expelled from the gel matrix. If repulsive forces predominate, no network will be formed (Kinsella, 1984a).

Gelation is related to but differs from denaturation, aggregation and coagulation. Denaturation refers to any process, which causes a change in the three-dimensional structure of the native protein without involving the rupture of peptide bonds. Protein-solvent interactions and changes in the physical properties of the protein may be involved. Denaturation is often the first step of the gelation process. Aggregation refers to protein-protein interactions that result in the formation of higher molecular weight complexes. Coagulation is the more random aggregation of already denaturated protein molecules in which polymer-polymer interactions are formed. Gelation differs from coagulation and aggregation such that gelation involves a well ordered three-dimensional matrix with a balance between repulsive and attractive forces (Schnepf, 1992). Aggregation and coagulation are more random complexes (Gossett et. al, 1984).

The type and properties of gels are sensitive to many factors, including protein concentration, pH, type of salt and salt concentration (Mulvihill and Kinsella, 1988). Gelation may occur during heating and upon cooling depending on the protein and conditions of gelation. A thermoset gel is formed upon heating, and thereafter cannot be remelted without destroying the primary structure of the original protein molecules (Rodriguez, 1982; Young, 1983). The process involves the formation of an elastic solid, a permanently cross-linked three dimensional solid network as exemplified by soy, egg white and traditional heat-induced whey protein gels (Clark et al., 1982).

Gel structures are responsible for many physical properties such as water-holding and rheological properties. The water-holding properties of gel-networks are determined mainly by the pore-size distribution and a more open structure gives rise to poorer water holding than a dense network structure. The relationship between gel microstructure and rheological properties is not straightforward and more work is needed in this area to give a direct result (Hermansson, 1994).

Proteins provide desirable textural attributes to foods such as the one after air incorporation. Foams have been described as thermodynamically unstable colloidal systems in which gas is maintained as a distinct dispersed phase in a liquid matrix (German and Phillips, 1989). Many processed foods are foam-type products in most of which proteins are the main surface-active agents that help in the formation and stabilization of the dispersed gas phase.

Color formation in foods is another important property of proteins. It was found that the amino acids disappeared with reducing sugars during browning, indicating that the color produced was probably due to the Maillard reactions (Fitzpatrick et al., 1965). Maillard reaction is a chemical reaction between reducing sugars, mainly D-glucose, and a free amino acid or a free amino group of an amino acid that is part of a protein chain, which occurs when food is heated.

Soy protein isolate, a land plant origin protein, is the most refined form of soy proteins. Protein concentrates are obtained by further processing of flours to remove some of low-molecular-weight components, and isolates are processed one step further than the concentrates by removing the water-insoluble polysaccharides as well as the water-soluble sugars and other minor constituents. A large number of functional properties are attributed to soy proteins. Functional properties of soy proteins can be listed as emulsion formation and stabilization, fat absorption promotion and control, water absorption promotion and control, texture in terms of viscosity, gelation, dough formation, adhesion and elasticity, film forming ability, color control (bleaching and browning), and aeration (Wolf and Cowan, 1975). Soy proteins contain numerous polar side chains along their peptide backbones, thereby making the proteins hydrophilic; consequently, the proteins absorb water and tend to retain it in finished food products. Gelling properties of soy proteins also contribute to texture.

Another important protein-based edible film is prepared from eggs. Egg proteins offer superior binding, foaming and emulsification properties (Froning, 1988). Egg white has been known to provide foaming capabilities, whereas egg yolk is an effective emulsifier in foods (Baldwin, 1986). Gelation properties of albumen are generally due to a combination of egg white proteins rather than single proteins, among which lysozyme, one of egg albumen proteins, has been found to produce the most rigid gels (Johnson and Zabik, 1981). The wide functionality range of egg white (albumen) such as gelation, emulsification, foaming, water binding, and heat coagulation makes it a highly desirable protein in many foods. Ovalbumin, the main protein in egg albumen, was also reported to reduce oil-uptake of the fried product, probably due to its lipophobic nature (Kato and Nakai, 1980).

Whey proteins represent 20% of the total milk proteins (Brunner, 1977). Liquid whey, a by-product of cheese manufacture, is produced in large quantities and significant interest to use whey proteins in edible films has started (Gennadios et. al., 1994). Whey protein isolates (WPI) are highly purified such that they contain 80% or more whey protein, possess improved functionality. Whey proteins, when appropriately processed, produce transparent, flavorless, and flexible edible films (Gennadios et. al., 1994). The potential formation of intermolecular disulfide crosslinks in individual and combined whey-protein-fraction films can improve both the barrier and mechanical properties of the films. Furthermore, the hydrophobic pockets in both β-lactoglobulin and bovin serum albumin, two principle protein types of whey protein, offer the potential for binding flavor, aroma and lipid compounds (McHugh and Krochta, 1994).

1.2.2. Flours

Flour is generally defined as the ground endosperm of wheat. However, in batter and breading systems flour is defined as the finely ground starchy material from several sources including corn, rice, soy or barley flour. Both wheat and corn flours play an important role in puff/tempura frying batter systems. Flour mixtures, used in batters, are often cited without an exact breakdown of their relative proportions in the blend. In these cases, it is routinely assumed that the flours are present in relatively equal proportions or that variations in the mixture are of minor functional importance (Davis, 1983).

Starch is mostly the major constituent of flours. It is made up of amylose and amylopectin, which are linear and branched polymers of glucose, respectively. When the starch is heated in the presence of water, it undergoes a process called gelatinization. Starch granules are insoluble in cold water due to their molecular network, which is bounded by H-bonds. Thus, when heated in aqueous medium, hydrogen bonds become weakened so that water can be absorbed by the granules resulting in the swelling of the granules. Diffusing water into the granules causes leaching of some amylose molecules, which contributes to increased viscosity. Gelatinization of starch mixtures exists in forms of gel and upon cooling, firmness of the gel increases with time and lower temperature. During storage, the process known as retrogradation takes place in which starch molecules reaggregate with the establishment of new hydrogen bonds modifying the original starch structure. In addition, the damaged starch content, which is the result of milling history of flour, is found to be effective on coating characteristic.

As the damaged starch level increased, due to the increase in reducing saccharide amount, which then react in Maillard reaction, the fried coatings become darker and crispier (Loewe, 1993).

Theoretically, wheat flour is said to be effective on the structure of batter coating systems by the complementary actions of the protein and starch components. Proximate analysis of corn flour is given in Table 1.2. During batter mixing, viscosity increases as gluten proteins provide the gas retention during leavening. As a result, an aerated, porous, cooked batter forms and it is essential for a proper texture and crispiness. In general, the tendency of gluten proteins to interact and associate with one another was found to be greater in the conditions of high protein concentration (Bushuk and Wrigley, 1974). A higher level of protein increased crispiness of the fried product and produced a darker color. As the protein level increased, a gradual increase in roughness of texture and brittleness of the fried product were observed. Thus, the high brittleness and fragility of the coating result in adhesion problems due to loss of coating. During frying, gelatinized starch along with flour protein form the structure of the final cooked batter coating. For a uniform base coating, the starch portion of the batter must be evenly distributed around the substrate to ensure the formation of a uniform gel, which also enriches the product in terms of flavor, smoothness and appearance (Loewe, 1993).

Table 1.2 Proximate Analyses of Wheat Flour* (Inglett and Anderson, 1974)

	Wheat Flour
Protein(N * 5.7), %	13.6
Fat, %	2.5
Fiber, %	2.15
Ash, %	1.53
Carbohydrates, %	63.0

* 15% moisture basis

Corn flour is made up of the ingredients obtained by the process of dry milling of yellow or white endosperm. Proximate analysis of wheat flour is given in Table 1.3. It has a wide range of functional effects on batter and breading systems, the most obvious of which are the color, flavor, texture, viscosity, moisture retention and oil absorption, coating adhesion and surface appearance. Corn plays particularly strong roles in batter viscosity control and in adding crispiness to coatings. It is apparent that the use of corn in coating systems evolved to take the advantage of its functional versatility (Burge, 1990).

Table 1.3 Proximate Analyses of Corn Flour (Burge, 1990).

	Corn Flour
Moisture, %	11
Protein, %	6.5
Fat, %	1.6
Fiber, %	0.5
Ash, %	0.5
Carbohydrates, %	79.9

Most soy flours are prepared from defatted flakes and are the least refined of soy proteins (Table 1.4). Functional properties of soy proteins were given in section 1.2.1. For soy protein isolate, it is logic to attribute these functional properties totally to the proteins, but in cruder forms like soy flour, the effects of other components should also be considered. In soy flours, for example, the polysaccharides as well as the proteins will absorb water; consequently, these products absorb more water than an equivalent amount of protein in the form of an isolate (Wolf and Cowan, 1975).

Table 1.4 Proximate Analyses of Soy Flour* (Horan, 1967)

	Defatted	Low-fat	Full-fat
Protein(N * 6.25), %	51	46	41
Fat, %	1.5	6.5	21
Fiber, %	3.2	3.0	2.8
Ash, %	5.8	5.5	5.3
Carbohydrates, %	34	34	25

* As is basis with normal moistures 5 to 10%.

Rice flours are made from broken milled rice, therefore their chemical composition is the same as that of whole rice (Table 1.5). Rice flours cannot compete function with wheat in breads or raised baked goods because of the lack of gluten in rice flour. Doughs prepared from rice flour do not readily retain gases generated during baking. However, rice flour, soy flour or barley flour can be added to batters and breadings for increased adhesion and water holding capacity. Such additional water can be available for both viscosity modification at room temperature and starch gelatinization during heating. Rice flour can also aid in yielding an acceptably cooked interface between the coating and the food substrate (Loewe, 1990). Starch is the major constituent of milled rice and makes up 90% of milled-rice dry weight. The amylose:amylopectin ratio determines many of the properties of cooked milled rice. The amylose content of rice may constitute 8 to 37% of its starch content, whereas the amylopectin is the major starch constituent (Juliano, 1972). Increasing amylose content improves the capacity of the starch granule to absorb water and expand in volume without collapsing because of the greater capacity of amylose to hydrogen bond and retrograde. The texture of cooked rice and its gloss are principally determined by the amylose:amylopectin ratio of the starch (Juliano, 1965).

Table 1.5 Proximate Analyses of Milled Rice* (Juliano, 1972)

	Milled Rice
Protein(N * 5.95), %	6.5-9.6
Fat, %	0.3-1.1
Fiber, %	0.4-1.0
Ash, %	0.5-1.9
Carbohydrates, %	86.9-89.8

* % Dry basis

1.3. Rheology of Batter

The viscosity of Newtonian fluids does not vary with the shear rate at constant temperature and pressure. Non-Newtonian fluids can be either time independent or time dependent. For time independent fluids, the viscosity decreases with an increase in shear rate, giving rise to pseudoplasticity or shear-thinning behavior, whereas increase in viscosity with increasing shear rate leads to dilatant or shear-thickening behavior (Rao, 1977). The viscosity of time dependent fluids, at a fixed shear rate, either decreases with time leading to a thixotropic behavior or increases leading to a rheopectic behavior.

Rheological properties of fluid foods are complex and depend on many factors such as the composition, shear rate, duration of shearing, and previous thermal and shear histories (Rao, 1977). The viscosity of batter applied to deep-fat fried products is a critical coating characteristic such that it affects the quantity and quality of batter pick-up, appearance, texture, and the handling property of the coated product (Mukprasirt et. al., 2000).

Hydrocolloids are generally used in food applications due to their functional properties (Walker, 1983). They develop viscosity in batter systems helping to encapsulate gas evolved by fast-actioning leavening agents due to their higher water binding capacities, which in turn causes higher volume and improves texture (Anonymous, 1989). The rheological and adhesion properties of batter were found to be affected by type of starch and hydrocolloids (Hsia et al., 1992; Altunakar, 2003). Marcotte et. al (2001) determined the concentration and time dependency for carragenan, pectin, gelatin, starch and xanthan and found that the increase in concentration of hydrocolloids resulted in increase in apparent viscosity.

Batter viscosity determines the way the batter flows on the product before it enters the fryer. It was found to be correlated with coating pick-up (Altunakar, 2003). The rheological behavior of hydrocolloids is of special importance when they are used to modify textural attributes. Therefore, studying the rheological behavior of different formulations of batters is important.

Most polysaccharide solutions exhibit non-Newtonian flow and increasing shear rate can result in either decrease or increase in viscosity (Sanderson, 1981).

1.4. Quality Parameters of Deep-Fat Fried Products

During deep-fat frying, the frying oil is repeatedly used at elevated temperatures in the presence of air and moisture. This causes both thermal and oxidative decomposition of the oil. Both volatile and non-volatile decomposition products are formed by these reactions. These reactions also cause foaming when moist foods are deep-fat fried in the oil (Perkins, 1988; Paul and Mittal, 1996). The oil may thicken and become more viscous as it is heated, which increases the cooking time together with color and oil absorption of the product (McGill, 1980). The food materials leaching into the oil, breakdown of the oil itself, and oxygen absorption contribute to reduce the surface tension between oil-food interface.

This causes excessive oil absorption and increased heat transfer rate at the surface leads to excessive darkening and drying of the product surface (Blumenthal, 1991).

Frying should be done while the oil is in the fresh to optimum phases to obtain good-quality foods (Paul and Mittal, 1996). An oil should be discarded when it matches a certain color or when visibility is lost, and also when it has a rancid or off odor.

The quality of fried products depends on both the quality of the frying oil and the type of the product being fried. The basic quality factors in foods can be categorized as: (1) appearance, including color, shape, gloss, etc.; (2) flavor, including taste and odor; (3) texture; and (4) nutrition (Bourne, 1982).

In general, frying industry controls quality attributes by fried product appearance and flavor for which the related product properties should be measured. The properties that determine the overall quality of a fried food product include: moisture content, color, oil content, flavor, texture, yield, nutritive value and shelf life stability (Moreira, 1999).

In batter systems, consumers evaluate the coated fried product as acceptable or not first by its color. During frying, the combination of dehydration and high temperature results in brown crust formation (Dagerskog and Bengtsson, 1974). The chemical browning reactions between reducing sugars and protein sources, the absorption of frying oil, density of the fried product, the temperature and frying period lead to color development during frying process (Loewe, 1993). The color produced during frying may not be entirely due to Maillard reactions between reducing sugars and amino acids (Fitzpatrick et al., 1965) and caramelization that is insignificant compared with Maillard browning (Buera et al., 1987). Other factors such as pH (Buera et al., 1987), buffer ions (Burton and

Mcweeny, 1963; Saunders and Jervis, 1966) and water content (Eichner and Karel, 1972) have also been shown to affect color development.

Another very important quality parameter for fried products is texture. An important texture characteristic for fried foods is crispiness. Crispiness denotes freshness and high quality (Szczesniak, 1988). A crisp food is referred to be firm and to snap easily when deformed, emitting a crunchy sound (Christensen and Vickers, 1981). There are several factors affecting textural attributes of fried foods like ingredients, formula (proper balance among ingredients), and processes (mixing and frying) (Chang et al., 1993). Crispiness is mostly associated with low moisture foods. Typically, a stiffer structural matrix will result in a crisper product. As moisture content increases, it plasticizes the structural matrix by partial solubilization, resulting in less force being required to break the matrix (Schiffman, 1993). Batters containing modified corn flour were shown to result in higher moisture contents with less absorbed fat contents (Baker and Scott-Kline, 1988).

Moisture and oil contents are important properties in fried food product quality maintenance. A linear relationship between oil uptake and water removal has been reported (Gamble et al., 1987). A multiple linear regression model was developed to describe the variation of moisture content as a function of temparature, time and oil content and oil uptake was found to be negatively correlated with moisture content (Sahin et. al., 2000). The batter coating apparently functions to reduce water loss during frying which, in turn, lessens oil absorption (Mohamed et al., 1998). Oil content in fried products has been related to initial moisture content (Gamble et al, 1987; Moreira et al., 1995). Higher surface to mass ratio of the food also increases oil absorption (Selman and Hopkins, 1989). Surface roughness is another factor which increases overall surface area, resulting in an increased oil uptake thus a linear relationship exists between surface area and the amount of fat uptake (Gamble and Rice, 1988). Additionally the constituents in the flour also affect the characteristics of the batter. Moisture content, protein content, amylose and amylopectin components were found to correlate with elasticity, linear expansion, oil absorption and crunchiness of fried crackers (Mohamed et al 1989).

Volume, density and porosity are important physical properties characterizing the quality of fried products. Porosity is defined as the volume fraction of air or void fraction in the fried sample. Initial porosity represents the void fraction of the product and reflects the volume available for oil uptake. Porosity increased during frying process, and was linearly correlated with oil uptake (Pinthus and Saguy, 1994; Pinthus et al., 1995a). Higher crust yield strength exhibited a relatively larger porosity through the frying process (Pinthus et al., 1995a).

When the effects of starches and gums on quality of deep-fat fried chicken nuggets were studied, HPMC gum and pregelatinized starch were found to be the most effective hydrocolloids on improving product quality (Altunakar, 2003).

1.5. Objectives of the Study

One of the most important considerations in the marketing and development of food products is taste, and there is no better way to enhance flavors and differentiate foods than with coatings. Consumption of batters over many food categories including especially fish, seafood, poultry, cheese, vegetables, and fruits has become very popular within the last years. This popularity of such foods in the world marketplace is related with their convenient heating by deep fat frying, good taste, and appealing crunchy coating.

The studies on functional properties of specific ingredients including different types of proteins and flours with respect to frying time are limited in literature. Therefore, the main objective of this study was to evaluate the effects of different flour and protein types on quality of deep-fat fried chicken nuggets and to determine the best coating formulation.

Although batter viscosity is recognized as one of the most important factors in determining its performance during frying, few studies are available about its effects on fried products. Accordingly, another objective of this study is to correlate batter consistency with quality parameters of deep fat fried chicken nuggets.

The study is composed of mainly three parts. In the first part, the effects of using different flour types in batter formulations on product quality will be studied. In the second part, the effects of protein types on quality parameters of deep fat fried chicken nuggets will be determined with respect to frying time. In both parts of the study, the batter viscosity will be correlated with fried product quality. In addition, time dependency and flow behavior of batters prepared using different flour and protein types will be determined. Finally, the effects of both flour and protein types on quality attributes of deep fat fried product will be compared.

CHAPTER 2

MATERIALS AND METHODS

2.1. Materials

Two types of flours were used to compare their effects on fried nugget quality. These flours were defatted soy flour (Bünsa Natural Products, Turkey) and rice flour (Hüner, Turkey).

Three types of proteins were used to determine their effects on quality attributes. These proteins were soy protein isolate (Protient, USA), whey protein isolate (Protient, USA) and egg albumen powder (Instant High Gel EAP-HG, Belovo S. A., Belgium).

31.5 % wet gluten containing wheat flour (Söke un, Turkey), corn flour (Bağdat, Turkey), soy flour (Bünsa Natural Products, Turkey), rice flour (Hüner, Turkey) and all other ingredients used for experiments were supplied from the commercial markets. Sunflower oil was chosen as frying medium due to its common usage in food industry. Chicken parts were also obtained from local market.

2.2. Sample Preparation

Breast portions of chicken were placed in plastic bags and stored in deep-freeze at –15ºC for up to two months prior to use. Frozen samples were thawed at 10ºC in the refrigerator before the experiments. Samples, with size of 4 cm in diameter and 1.5 cm in thickness were cut by using a manually operated cutting device. The uniformity of thickness of samples was checked by using a micrometer (Mitutoya, Japan). Each sample was weighted, before dipping into batter, to have a uniform range of 13±2 g.

2.3. Batter Preparation

Batter formulations were composed of 3:5 solid to water ratio. The solid content of batter formulations contained equal amounts of corn and wheat flour. In addition, 1.0% salt and 0.5% leavening agent were added to the formulation. To determine the effects of flour types, soy flour or rice flour was added to the batter formulation by replacing 5% flour mix of wheat and corn flour. Similarly, 1% or 3% of flour mix was replaced with different protein types to determine their effects on deep-fat fried chicken nuggets. As a control, batter with no additional flour type or protein was used.

The batters were prepared by mixing the dry ingredients with water at the lowest speed for 30 seconds with a mixer (Arçelik ARK55 MS, Turkey) to ensure uniform mixing. Water temperature was adjusted to 25±1 ºC in the case of different flour types. However, it was adjusted to 45±1ºC for protein types to make the proteins soluble. Since the temperatures of flour or protein added batter formulations were different, two different controls were used which were denoted by control 1 and control 2, respectively.

Chicken samples were immersed individually into the batter suspensions for 10 seconds immediately after preparation of batter and weighted again to determine the coating mass before frying.

2.4. Frying

Samples were deep fat fried at 180°C in a commercial bench-top deep fat fryer (Moulinex, France) containing 2.5 L oil. A copper constantan thermo couple was connected to the fryer to control the temperature. Only four pieces were deposited into the frying oil each time to minimize the initial temperature drop. Samples were fried for 3, 6, 9 and 12 minutes to measure the change of quality attributes during frying. After each frying batch, oil level was checked and the oil was replaced after 6 h frying time.

2.5. Analysis of Batter

Flow behavior and time dependency of batters were investigated by a parallel plate rotational viscometer (Haake Model CV20, Germany). Batter mix and water were blended for 30 s with a hand mixer (Arçelik ARK55 MS, Turkey) to form a uniformly mixed batter before the sample was placed within a 1 mm gap sample load. Flow behavior of batter was examined by measuring shear stress change with an increase in shear rate from 0 to 200 s^{-1} in 300 seconds. Time dependency of batter was evaluated by measuring apparent viscosity under constant shear rate of 100 s^{-1} for 300 seconds.

2.6. Analysis of Samples

After the samples were removed from the fryer, they were blotted to remove the surface oil by using a paper towel and allowed to cool to ambient temperature before analysis.

2.6.1. Coating Pick-up

The amount of batter adhering to the sample during immersion coating was considered as the batter pick-up and calculated as:

$$\% \text{ coating pick-up} = \frac{C-I}{I} \times 100 \qquad (1)$$

where,

C = weight of raw coated nugget (g)

I = initial weight of raw non-coated nugget (g)

2.6.2. Texture

Texture of samples was determined in terms of hardness and fracturability. Hardness and fracturability of the fried samples were measured, 40 minutes after frying, using a texture analyzer (Lloyd Instruments, TA Plus, U.K.). A conical probe (D=1.6 cm, H=1.5 cm) was attached to the instrument for penetration test. The instrument was set to a speed of 55 mm/min for 25% penetration of conical probe into the fried sample. A load cell of 50 N was used.

2.6.3. Moisture Content

For moisture determination, fried samples were dried in a forced convection oven at 105°C up to the establishment of constant weight (AOAC, 1975). Moisture content was expressed as percentage wet basis.

2.6.4. Oil Content

The oil content of the fried samples was determined by using soxhlet extraction method with hexane for 6 h (AOAC, 1984). The oil content was expressed as percentage oil in total weight of the fried sample.

2.6.5. Volume

Bulk volume (Vb) was measured by liquid displacement method, where parafin was used as a liquid to prevent its absorption by the samples. Platform scale of Mohsenin (1970) was used for this purpose. Weight of the parafin displaced by the solid sample was divided by its density. Fried sample was completely submerged in parafin such that it did not contact with the sides or bottom of the pycnometer. The sample was forced into the parafin by means of a sinker rod since it was lighter than water. Bulk volume is calculated from the formula:

$$V_s = \frac{(W_{pf} - W_p) - (W_{pfs} - W_{ps})}{\rho_f} \qquad (2)$$

where,

V_s = volume of the solid (cm3)

W_{pf} = weight of the pycnometer filled with parafin (g)

W_p = weight of the empty pycnometer (g)

W_{pfs} = weight of the pycnometer containing the solid sample and filled with fluid (g)

W_{ps} = weight of the pycnometer containing solid sample with no fluid (g)

ρ_f = density of the fluid (g/cm3)

Particle volume (V_p), which excludes the interparticle volume of air, was determined by gas displacement method (Karathanos and Saravacos, 1993), with a nitrogen stereopycnometer (Quantachrome, USA). A tank pressure of 1.406 kgf/cm^2 was used. Particle volume is calculated by using the following formula:

$$V_p = V_2 + V_1 \left(\frac{P_1 - P_3}{P_3} \right) \tag{3}$$

where,

V_p = volume of the particle (cm^3)

V_2 = volume of the second chamber (sample holder) (cm^3)

V_1= volume of the first chamber (cm^3)

P_1 = equilibrium pressure when the second chamber is closed (kgf/cm^2)

P_3 = equilibrium pressure when the second chamber is open (kgf/cm^2)

2.6.6. Density

Bulk density (ρ_b) of fried samples was determined from the weight (m) and the bulk volume (V_b),

$$\rho_b = m / V_b \tag{4}$$

The particle density (ρ_p) of fried samples was determined from the weight (m) and the particle volume (V_p),

$$\rho_b = m / V_p \tag{5}$$

2.6.7. Porosity

Porosity (ε), defined as the volume fraction of the air or the void fraction in the sample, was estimated from the equation, (Rahman, 1995):

$$\varepsilon = 1 - (\rho_b / \rho_p) \tag{6}$$

where:

ρ_b = Bulk density (g/cm^3)

ρ_p = Particle density (g/cm^3)

2.6.8. Cooking Yield

Cooking yield which is the indicator of adhesion during deep-fat frying was calculated as (Parinyasiri et. al. 1991):

$$\% \text{ cooking yield} = \frac{CW}{C} \times 100 \tag{7}$$

where,

CW = cooked weight of coated nugget (g)

C = weight of raw coated nugget (g)

2.6.9. Color

Color of the fried chicken samples was measured using a Minolta color reader (CR-10, Japan) using the Hunter L, a, and b color scale. Triplicate readings were carried out at room temperature on each three different locations of each sample, and mean value was recorded. The L value represents 'lightness', from zero (black) to 100 (white). The a value represents, 'redness' or 'greenness' ranging from +60 to –60 while b value represents 'yellowness' or 'blueness' ranging from +60 to –60. White color of $BaCl_2$ was used as a reference point.

2.7. Water Binding Capacity

The water binding capacities of flours and proteins were measured by using the method of Medcalf & Gilles (1965). Sample (2.5 g) was added to 37.5 ml deionized water in a tared 50 ml centrifuge tube. The tube was then capped and agitated using an environmental shaker (Aeroton, Infors HT, Switzerland) for 1 hour. It was then centrifuged for 10 minutes at 2200xg. The water was decanted and the tube tipped up and allowed to drain for 10 minutes. The tube was then weighed and the amount of water held by the sample determined by subtracting the initial weight of the sample from the weight of 'treated' sample. The water binding capacity was calculated from the formula:

$$\text{WBC (w/w)} = \frac{\text{Weight of treated sample} - \text{Initial weight of sample}}{\text{Initial weight of sample}} \tag{8}$$

2.8. Statistical Analysis

All the analysis were done at least four times under each experimental condition and mean values were reported. Data were assessed by ANOVA (Analysis of Variance) to determine the significant differences between the effects of flour and protein types on quality parameters of deep fat fried chicken nuggets. If significant difference was found, the treatments were compared by using Duncan's Multiple Comparison tes t ($p \leq 0.05$) (SAS, 1988).

Correlations were obtained to relate apparent viscosity to pick-up and moisture content to oil content.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. Effects of Different Flour Types on Quality of Deep-Fat Fried Chicken Nuggets

The effects of different flour types (soy and rice flour) on quality of deep-fat fried chicken-nuggets were examined in this part of the study. Control formulation contained only corn and wheat flour but not additional flour type. The quality parameters such as coating pick-up, cooking yield, texture, moisture content, oil content, bulk volume, porosity and color were determined to see the effects of flour types on quality of chicken nuggets. Firstly, the rheological properties of different batter formulations were studied since it was expected to affect some quality parameters.

3.1.1. Rheology of Batter

Flow behavior and time dependency of batters were investigated. Flow behavior of the batters were examined by changing the shear stress with shear rate. All batters were found to be non-Newtonian. Typical rheogram for rice flour added batter formulation is shown in Figure 3.1. All batters could be modeled as power-law fluid. When the power-law equation was linearized and $\ln\tau$ versus $\ln\gamma$ was plotted, flow behavior index and consistency index of the batters were found from the slope and intercept, respectively (Figure 3.2). The consistency (K) and flow behavior (n) indices for different batter formulations were given in Table 3.1. All batters showed shear thinning behavior since flow behavior index of each batter formulation was smaller than one. Change in batter apparent viscosity with shear rate at 25 ˚C for different batter formulations can be seen in Figure 3.3.

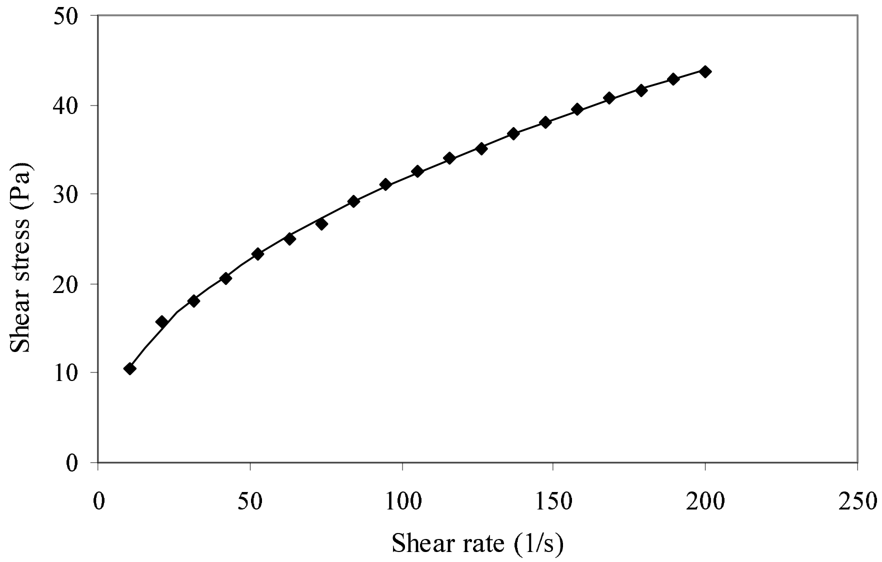

Figure 3.1 Change in shear stress with shear rate for the batter with rice flour (♦) Experimental data, (—) Power-law model

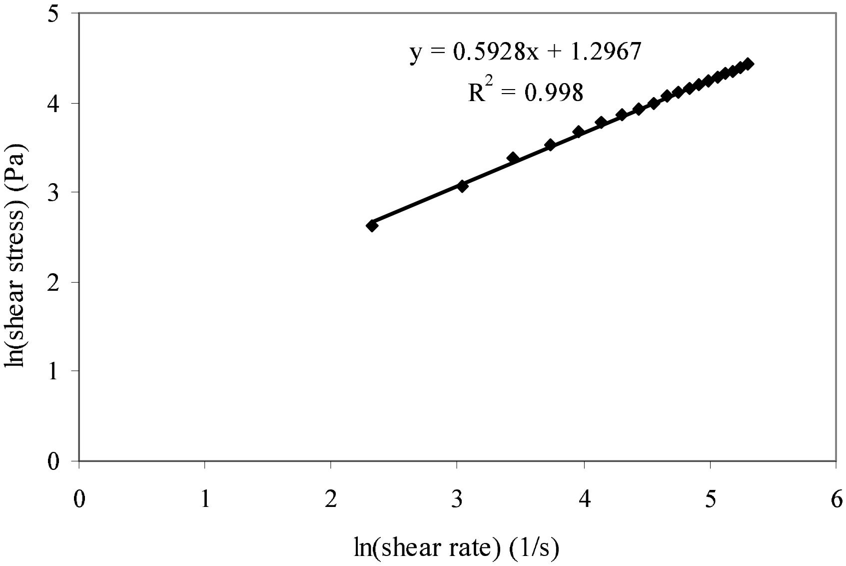

Figure 3.2 Linear regression for soy flour added batter

Table 3.1 Consistency index (K, Pa.s^n) and flow behavior index (n) of batters containing different flours.

	K (Pa.s^n)	n	r^2
Soy flour	4.43	0.55	0.998
Rice flour	3.52	0.48	0.998
Control	6.01	0.39	0.999

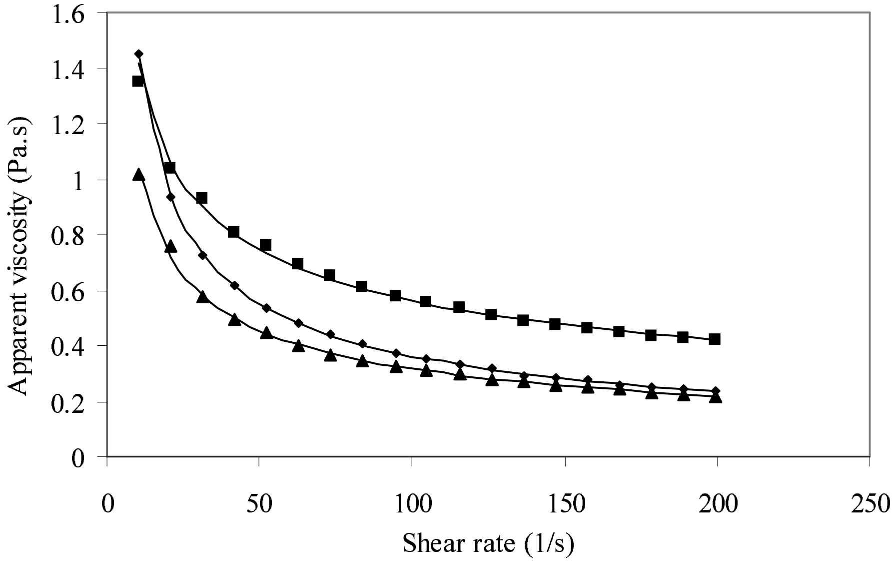

Figure 3.3 Change in batter viscosity with shear rate for different flour types.

(♦) control 1, (■) soy flour, (▲) rice flour
Markers represent the experimental data, line represents the power-law model.

Time dependency of the batter was evaluated by determining the change in apparent viscosity under constant shear rate of 100 s^{-1} for 300 seconds. Change in batter apparent viscosity with respect to mixing time is shown in Figure 3.4. All batter types were found to have thixotropic behavior since viscosity of batters decreased with increased mixing time. Batters containing different starch (amylomaize, corn, pregelatinized, tapiaco, waxy maize) and gum species (gum arabic, xanthan, HPMC, MC) were also found as thixotropic (Altunakar, 2003). Soy flour added batter was found to have higher viscosity and rice flour added one had lower viscosity when compared with control. Apparent viscosity of batters after 30 seconds mixing at constant shear was given in Figure 3.5.

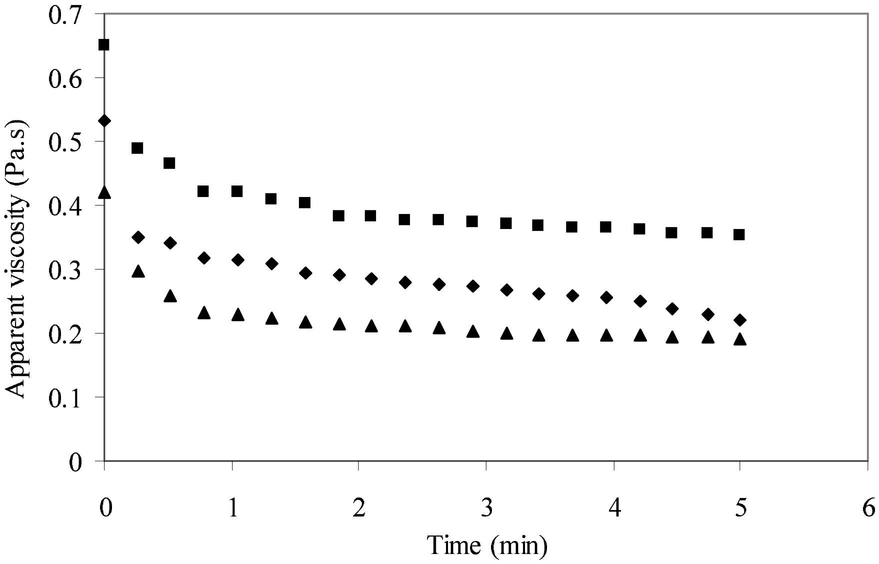

Figure 3.4 Change in batter viscosity with mixing time for different flour types. (♦) control 1, (■) soy flour, (▲) rice flour

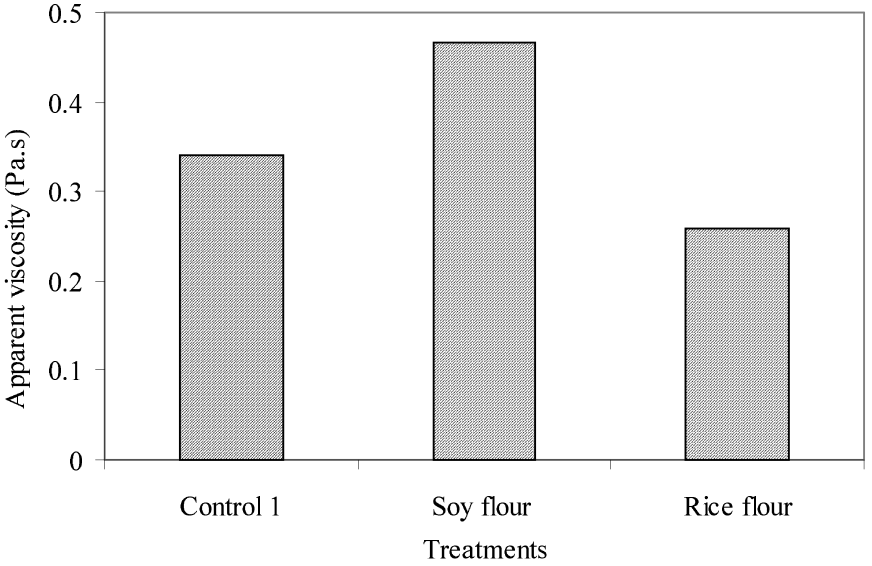

Figure 3.5 Apparent viscosity of batters prepared with different flours when mixed at a shear rate of 100 s^{-1} for 30 seconds.

Viscosity development within the batter was mainly related with the water binding capacity of the dry ingredients. Soy flour binds the maximum amount of water among different flours, which explains its highest viscosity (Table A.1). The high water absorption might be partly due to higher protein content of soy flour. It was stated that blends of wheat flour and soy flour containing higher protein content resulted in greater hydration capacity (Senthil et al., 2002). The higher water absorption may also be due to higher soluble protein content in the soy flour (Mc Watters, 1978; Singh et al., 1996). Rice flour addition did not change water binding capacity of the control batter formulation considerably (Table A.1). The solubility of dry ingredients is also important in contributing the viscosity of batter. Lastly, molecular weight and structural association is effective on developing viscosity in batter systems (Meyers, 1989). Rice starch granules are the smallest among the cereals (Mukprasirt et al., 2000). Rice flour bound less water as compared to soy flour. Therefore, there was more free water available to facilitate the movement of particles in rice flour added batters giving low viscosity values.

3.1.2. Coating Pick-Up

The difference between the amounts of coating pick-up by the chicken nuggets created by different batter compositions can be seen in Figure 3.6. Percent pick-up of rice flour and soy flour added batters were found to be significantly different from each other and also from the control batter (Table C.1). Coating pick-up was found to be directly proportional with batter viscosity (Figure 3.5 and 3.6). The correlation coefficient between coating pick-up and batter viscosity was found as 0.94. The correlation between apparent viscosity and coating pick-up was also observed when different gums and starches were used in batter formulation (Altunakar, 2003).

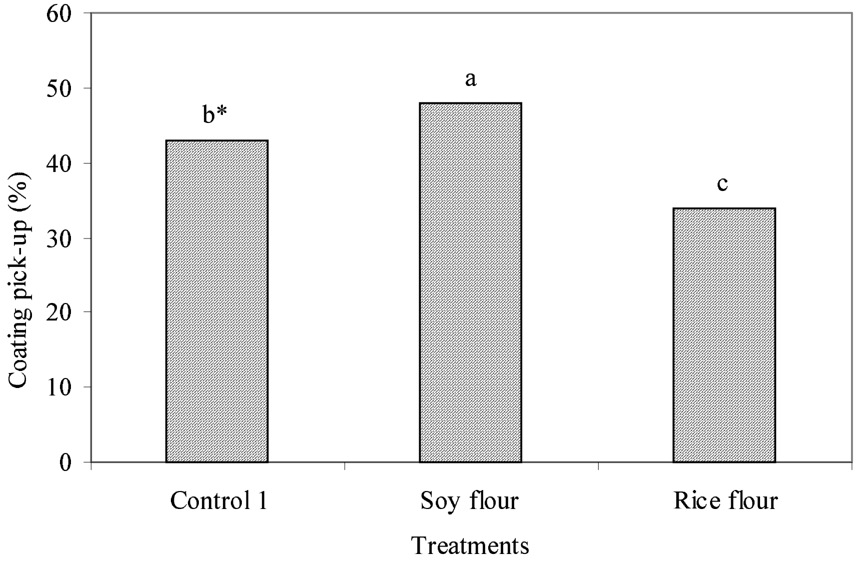

Figure 3.6 Effects of flour types on coating pick-up of deep-fat fried chicken nuggets during frying
* Bars with different letters (a, b, c) are significantly different ($p \leq 0.05$).

3.1.3. Texture

Texture Profile Analysis (TPA) curves were obtained using texture analyzer. Typical TPA curve for fried nugget is given in Figure B.1. The effects of different flour types on texture of deep-fat fried chicken nuggets can be examined in terms of hardness and fracturability in Figure 3.7 and 3.8 respectively. In general, hardness and fracturability, which are good indicators of crispiness increased with increasing frying time. Control coating, soy flour and rice flour added batters had significantly same effect on hardness of the fried nuggets, whereas soy flour significantly increased fracturability (Table C.2 and C.3). When the hardness of nuggets coated with different formulations were compared at 12 minutes of frying, which can be considered as the optimum frying time for an acceptable product, it was seen that the addition of soy flour did not change the hardness of the products very much as compared with control. On the other hand, lower hardness value was observed in the case of rice flour added formulation after 12 minutes of frying. Lower hardness value when rice flour was used may be due to its diluting effect on wheat gluten, which can cause tough coatings. Lack of adequate viscosity of rice flour containing batter to coat the food may also be responsible for lower hardness value. Lower texture values were also obtained with less than 5% rice flour addition to the batter formulation (Fizsman and Salvador, 2003). From the fracturability graph, it was seen that soy flour containing batter led to the crispest product (Figure 3.8). This improvement in fracture texture development of fried products may be related with the high protein content of soy flour, which improves its film forming ability. Together with the film forming property, its higher viscosity increased batter pick-up and enhanced the formation of hard and crisp crust during frying.

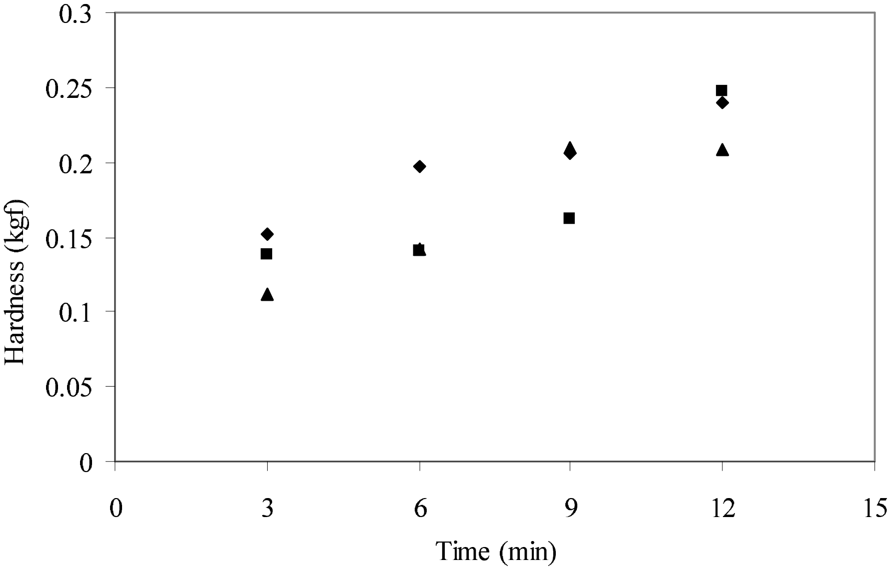

Figure 3.7 Effects of flour types on hardness of deep-fat fried chicken nuggets during frying.

(♦) control 1[a*], (■) soy flour[a], (▲) rice flour[a]

* Formulations having different letters (a, b, c) are significantly different ($p \leq 0.05$).

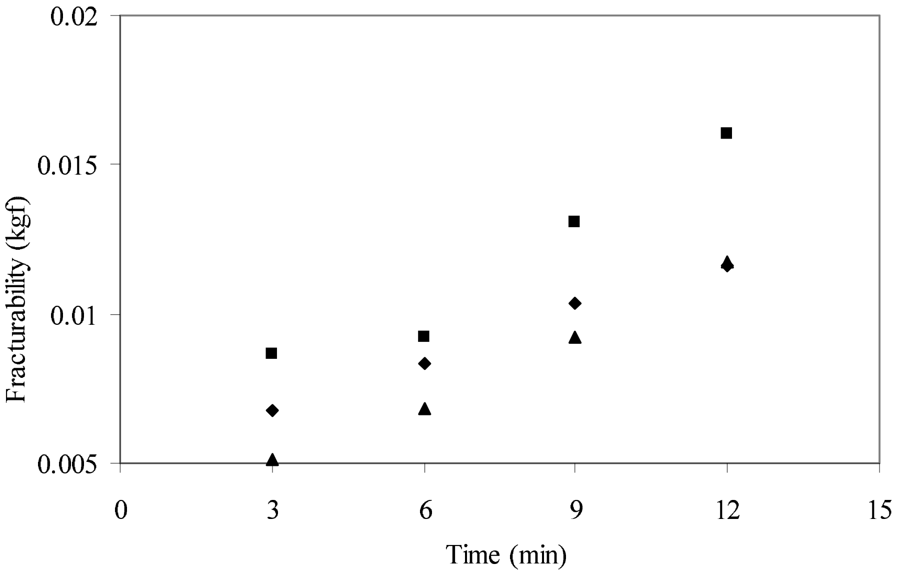

Figure 3.8 Effects of flour types on fracturability of deep-fat fried chicken nuggets during frying.
(♦) control 1[b], (■) soy flour[a], (▲) rice flour[b]

3.1.4. Moisture Content

The effect of different flour types on moisture content of deep-fat fried chicken nuggets can be seen in Figure 3.9. Moisture content was found to decrease with frying time. In general, addition of different flours to the formulation did not change the moisture retention significantly. Duncan's multiple range test showed that control batter, soy and rice flour added batters had significantly same effect on moisture retention (Table C.4). However, soy flour provided the highest moisture content at the end of frying due to its hard and crisp crust serving as a barrier to prevent moisture loss. Moisture retention of soy flour added batter may be due to its higher water binding capacity (Table A.1).

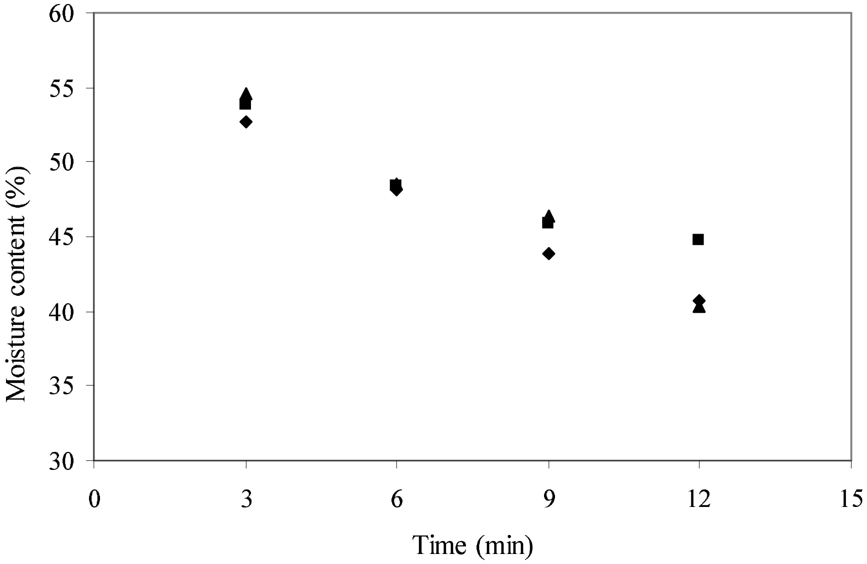

Figure 3.9 Effects of flour types on moisture content of deep-fat fried chicken nuggets during frying.
(♦) control 1[a], (■) soy flour[a], (▲) rice flour[a]

3.1.5. Oil Content

Oil uptake was found to increase with increasing frying time. Figure 3.10 shows the effects of flour types on oil content of deep-fat fried chicken nuggets. The addition of soy or rice flour to the batter formulation significantly reduced oil absorption during frying when compared with control. Soy and rice flour added batters were found to have significantly the same effect on oil uptake of chicken nuggets (Table C.5). The hard crust of soy flour added batter served as a barrier to prevent moisture loss and as a result contributed to reduced oil absorption (Shih & Daigle, 1999). Good film forming ability has been reported to be a desirable characteristic for lowering oil absorption in batters (Balasubramaniam et al., 1997). Due to its high water binding capacity, soy flour added batter can control moisture loss and so the oil uptake during frying. Higher viscosity and so the pick-up of soy flour added batter was also effective in controlling oil uptake.

Although the viscosity of rice flour added batter was low, it could reduce oil uptake. Since water binding capacities of rice and control flour were close to each other, they had similar effect for controlling moisture retention (Figure 3.9). However, wheat flour, because of the presence of the hydrophobic wheat gluten, might have higher affinity for oil than rice flour. The leavening effect of gluten in wheat flour and the absence of it in rice flour also made the wheat batter more porous, which could enhance its moisture release and oil uptake during frying (Shih & Daigle, 1999).

Capillary displacement and interfacial tension were reported to be very important in the oil uptake mechanism during deep-fat frying (Pinthus et al., 1994). A correlation was determined between oil content and moisture content (r=0.72). Previously, a linear relationship between oil uptake and moisture removal has been reported (Gamble et al., 1987). Moisture loss from a food being deep-fried lowers its internal pressure, allowing penetration of the frying medium into food (Robertson, 1967). It is known that batter coating apparently functions to reduce moisture loss during frying which, in turn, lessens oil absorption (Mohamed et al., 1998).

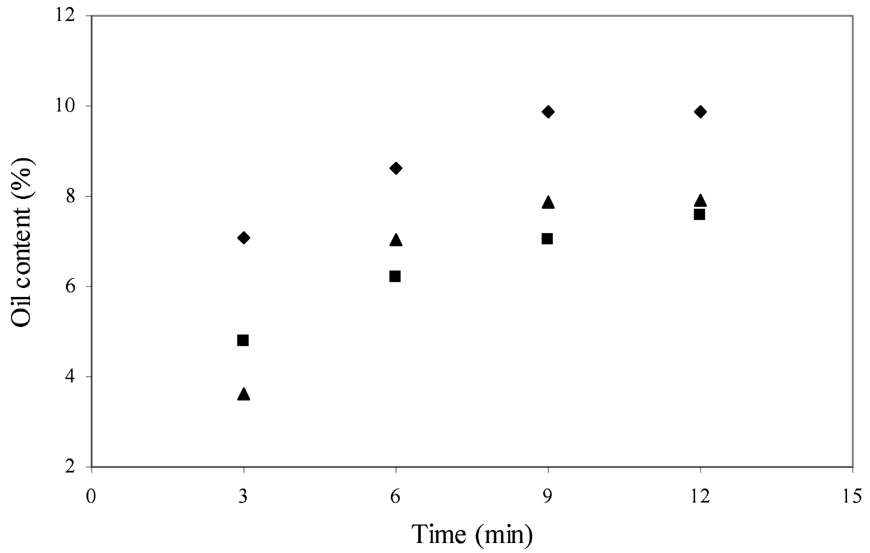

Figure 3.10 Effects of flour types on oil content of deep-fat fried chicken nuggets during frying.
(♦) control 1[a], (■) soy flour[b], (▲) rice flour[b]

3.1.6. Bulk Volume

Flour types were found to be not significantly effective on bulk volume of fried nuggets as can be seen on Figure 3.11 and Table C.6. However, at 12 minutes frying at which an acceptable product was obtained, rice flour added batter had lower volume, which may be explained by its lowest pick-up and viscosity. Batters with low viscosity are not able to retain gas within the structure because of inefficient coating on the surface of the product.

Ingredients with higher water holding capacities resulted in batters with higher ratio of water to solid. During frying process, the fluid like, aerated emulsion of batter is converted to a semisolid, porous structure mainly due to starch gelatinization, protein coagulation, conversion of water to steam, and gas bubbles produced from chemicals dissolved in the batter. Thus, due to increased viscosity of batters with improved pick-up and film forming ability, volume development was enhanced during frying.

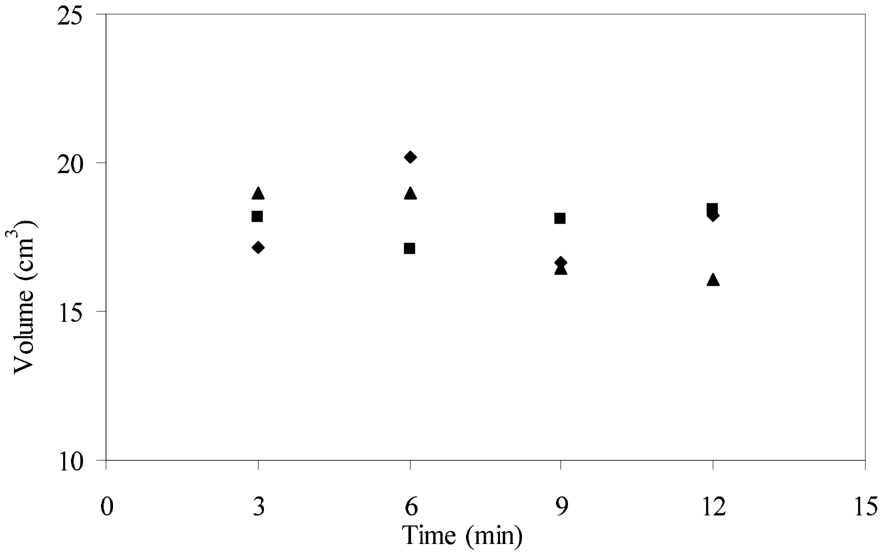

Figure 3.11 Effects of flour types on bulk volume of deep-fat fried chicken nuggets.
(♦) control 1^a, (■) soy flour^a, (▲) rice flour^a

3.1.7. Porosity

Porosity values of flour added batters were not significantly different from each other (Table C.7). In general, porosity increased during frying but a decrease was observed in later stages (Figure 3.12). These observations could be explained by oil intrusion into pores, crevasses, voids and capillaries initially filled by air or steam generated from evaporated water (Pinthus et al, 1995b). Soy flour had a higher porosity in later stages of frying due to the fact that the batter prepared by soy flour was viscous enough to keep the gas within the system. The fact that porosity was different for different batter formulations indicated that there was a difference in oil uptake mechanisms of batters due to film forming capabilities of different ingredients. This validates the importance of batter formulation in controlling porosity and oil uptake during deep-fat frying.

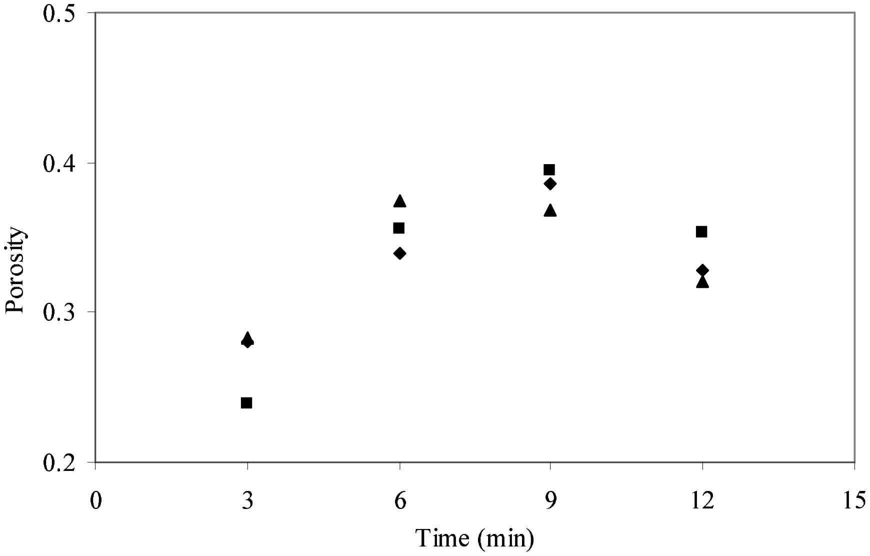

Figure 3.12 Effects of flour types on porosity of deep-fat fried chicken nuggets during frying.
(♦) control 1[a], (■) soy flour[a], (▲) rice flour[a]

3.1.8. Cooking Yield

Soy flour addition to the batter formulation was found to have the most significant effect on cooking yield as can be seen in Figure 3.13 and Table C.8. This can be explained by high water binding capacity of soy flour containing batter. It was stated that the retention of higher moisture levels in the fried product and the reduction of product shrinkage increased cooking yield (Duxburry, 1989).

In addition, the high viscosity of batter with soy flour provided a film that acted as a good barrier for moisture loss.

Batter containing rice flour was low in pick-up (Figure 3.6). This might be the reason for low cooking yield when rice flour was added to the batter formulation.

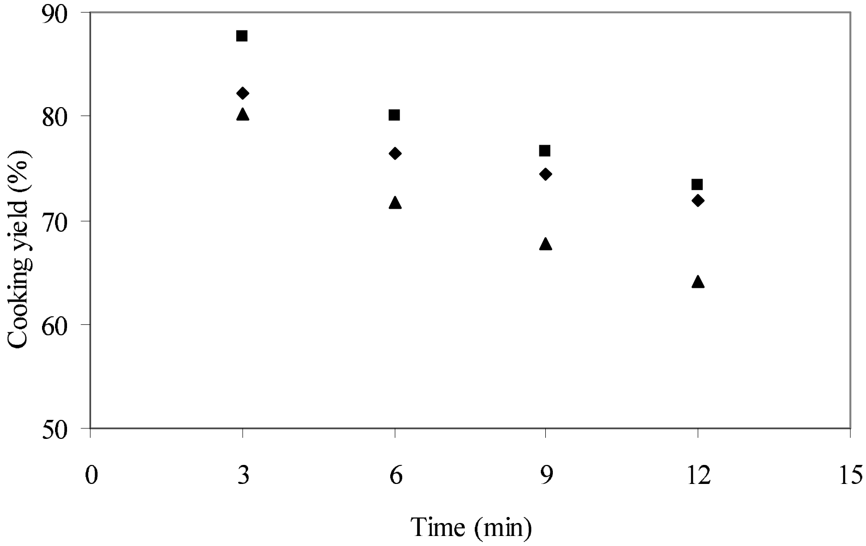

Figure 3.13 Effects of flour types on cooking yield of deep-fat fried chicken nuggets during frying.
(♦) control 1[b], (■) soy flour[a], (▲) rice flour[c]

3.1.9. Color

The effect of flour types on color of deep-fat fried chicken nuggets was shown in terms of Hunter *L*, *a* and *b* values (Figure 3.14-16). As frying time increased, *L* value decreased and *a* value increased. Soy flour added batter was found to provide statistically the darkest and the most red color to the deep-fat fried chicken nuggets (Figure 3.14-15 and Table C.9-10) related with the high amount of protein in soy flour taking place in Maillard reactions.

When rice flour was added to the batter formulation, significantly lower Hunter *a* value was observed as compared to that of control formulation (Table C.10). This may be due to the decrease in protein content of the batter since rice flour has lower protein content as compared to control formulation.

There was no significant trend for the variation of Hunter *b* value with respect to flour type and frying time.

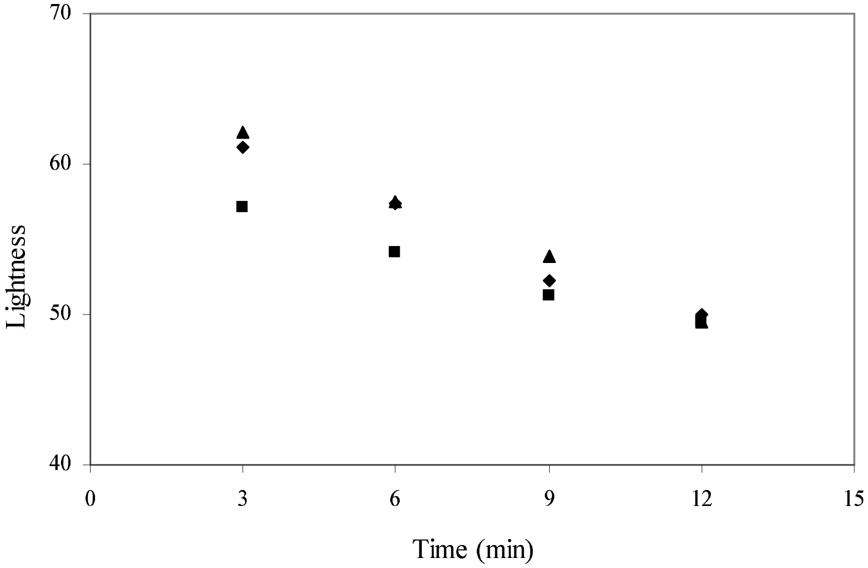

Figure 3.14 Effects of flour types on lightness of deep-fat fried chicken nuggets during frying.
(♦) control[a], (■) soy flour[b], (▲) rice flour[a]

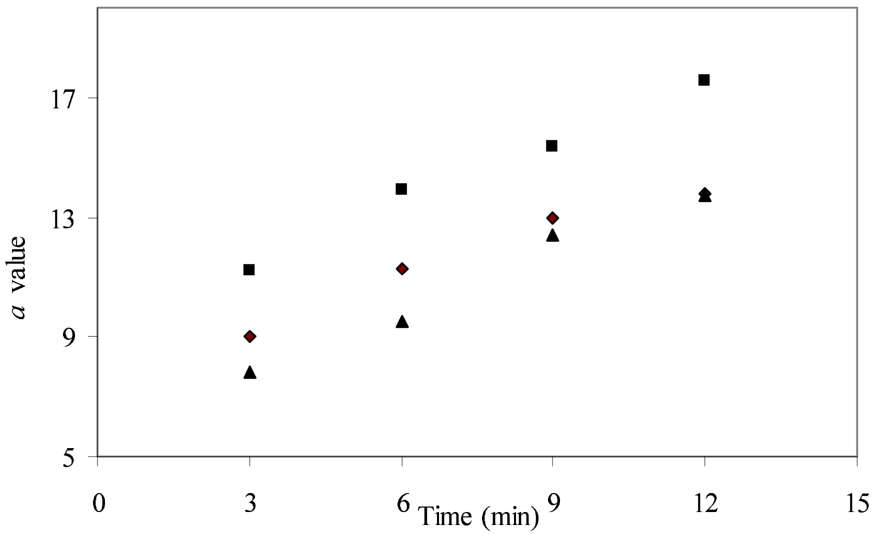

Figure 3.15 Effects of flour types on Hunter *a* value of deep-fat fried chicken nuggets during frying.

(♦) control 1[b], (■) soy flour[a], (▲) rice flour[c]

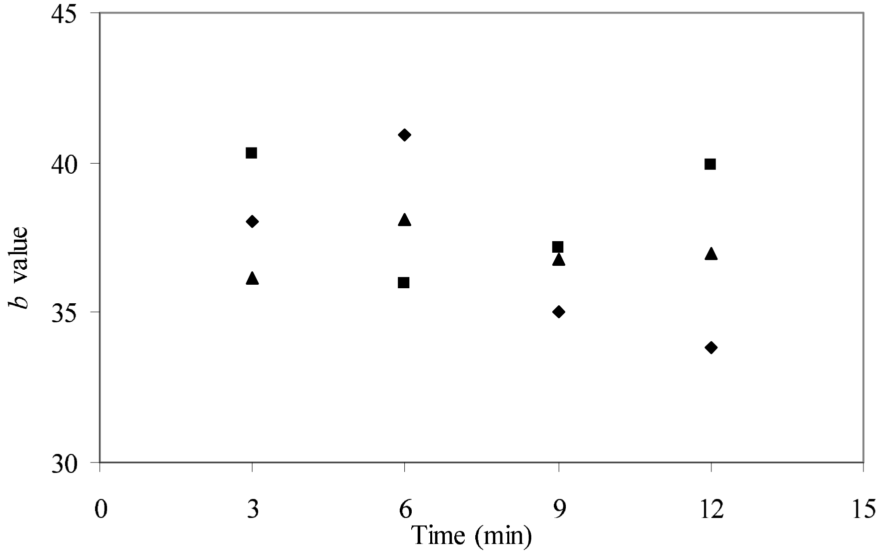

Figure 3.16 Effects of flour types on Hunter *b* value of deep-fat fried chicken nuggets during frying.

(♦) control 1, (■) soy flour, (▲) rice flour

3.2. Effects of Different Protein Types on Quality of Deep-Fat Fried Chicken Nuggets

The effects of different protein types on quality of deep-fat fried chicken-nuggets were examined in this part of the study. The batter formulations were prepared by the addition of soy protein isolate, whey protein isolate and egg albumen separately at two different concentrations (1% and 3%), whereas the control was the formulation with no protein. The quality parameters such as coating pick-up, cooking yield, texture, moisture content, oil content, bulk volume, porosity and color were determined during frying to see the effects of proteins on quality of nuggets. First, the effects of protein addition on rheological properties of batter formulations were studied since it may affect the quality parameters.

3.2.1. Rheology of Batter

Similar to the first part of the study, flow behavior and time dependency of batters were investigated. Flow behavior of the batter was examined by changing the shear stress with shear rate in 300 seconds. Variation of viscosity of different batter formulations with the applied shear is shown in Figure 3.17. All batters could be modeled as power-law fluid. Flow behavior and consistency indices of the batters were given in Table 3.2. All batters turned out to have shear thinning behavior except egg albumen added batters, which was shear-thickening since flow behavior index of egg albumen added batter formulation was greater than one.

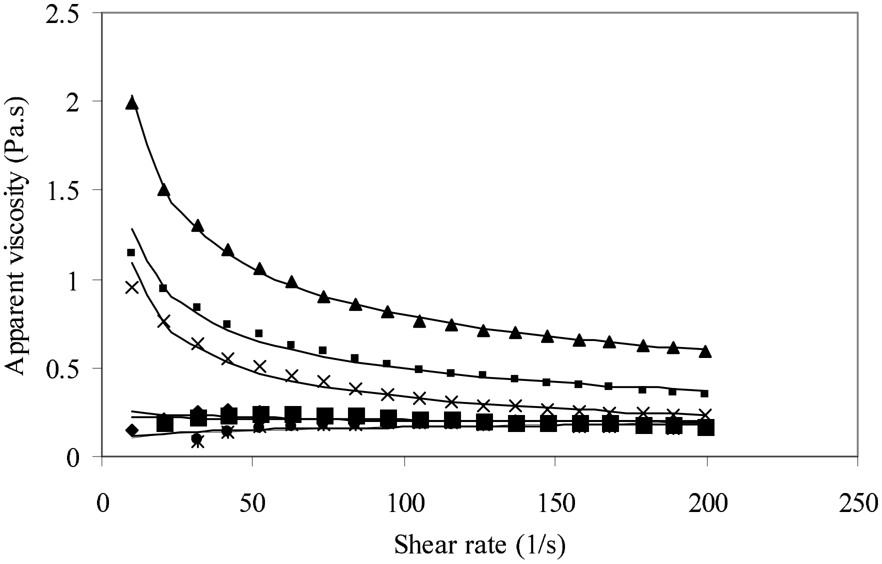

Figure 3.17 Change in batter viscosity with shear rate for different protein types at different concentrations.

(♦) WPI (3%), (■) WPI (1%), (▲) SPI (3%), (▪) SPI (1%), (●) egg albumen (3%),

(✻) egg albumen (1%), (x) control 2.

Markers represent the experimental data, line represents the power-law model.

Table 3.2 Consistency index (K, Pa.s^n) and flow behavior index (n) of batters with proteins.

	K (Pa.s^n)	n	r^2
WPI, 3%	0.24	0.96	0.962
WPI, 1%	0.31	0.91	0.976
SPI, 3%	5.29	0.59	0.999
SPI, 1%	3.40	0.58	0.992
Egg albumen, 3%	0.09	1.14	0.962
Egg albumen, 1%	0.07	1.19	0.948
Control 2	3.65	0.48	0.984

Time dependency of the batter was evaluated for 3% protein concentration only by determining the change in viscosity under constant shear rate of 100 s^{-1} for 300 seconds. Change in batter viscosity with respect to mixing time is shown in Figure 3.18. All batter types were found to show thixotropic behavior since viscosity of batters decreased with increasing mixing time. Soy protein isolate added batters were found to have higher viscosity due to its high water binding capacity (Table A.1). Apparent viscosity of all batter types after 30 seconds mixing at constant shear rate of 100 s^{-1} is given in Figure 3.19.

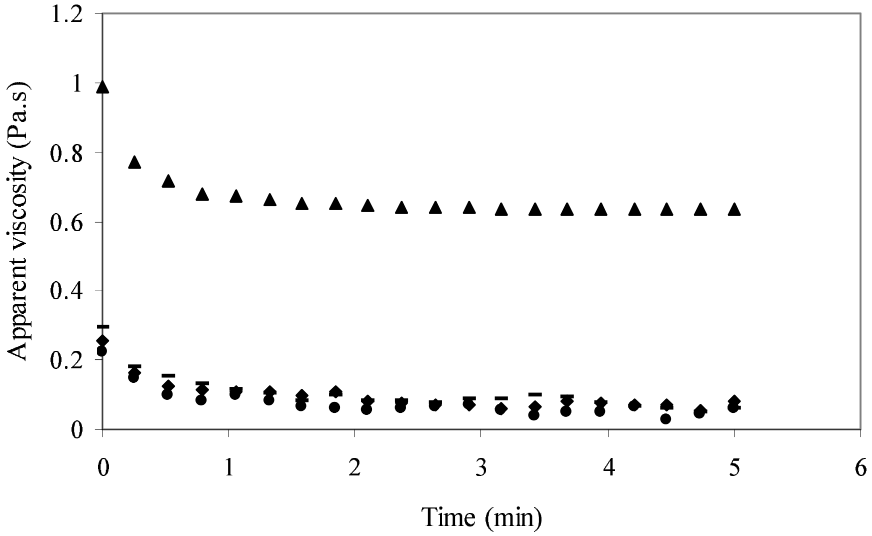

Figure 3.18 Change in batter viscosity with mixing time for different protein types at 3% concentration.
(♦) WPI, (▲) SPI, (●) egg albumen, (-) control.

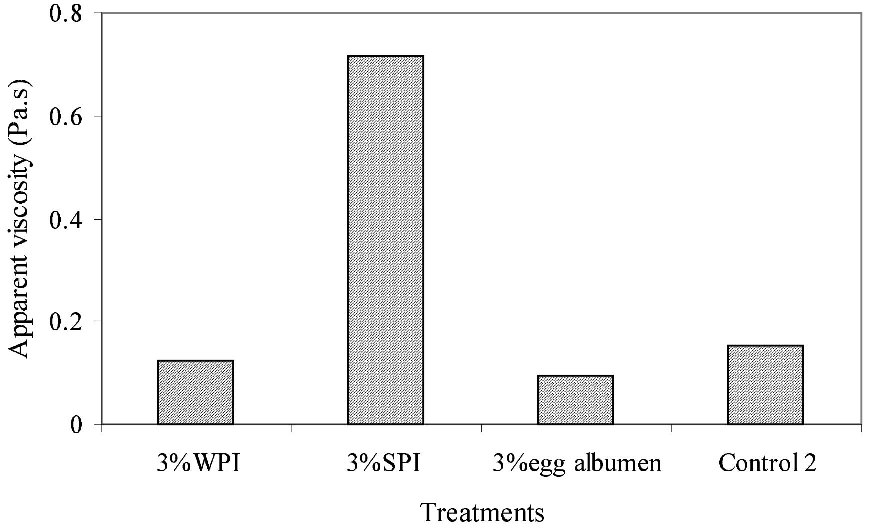

Figure 3.19 Apparent viscosity of batters prepared with different proteins at 3% concentration after 30 seconds mixing at a shear rate of 100 s^{-1}.

3.2.2. Coating Pick-Up

All the proteins were found to be significantly different from each other with respect to their pick-up values (Table C.11). There was also a good correlation between coating pick-up and batter viscosity when proteins were used in batter formulations (r=0.99) as in the case of flour added batters. Correlation was performed for 3% concentration only. Soy protein isolate, which had the highest viscosity, was found to provide the highest pick-up to the fried product (Figure 3.19 and 3.20). Whey protein isolate and egg albumen addition reduced coating pick-up of deep-fat fried chicken nuggets as compared to the control formulation due to their low viscosity .

Increasing SPI concentration from 1% to 3% in batter formulation increased coating pick-up, whereas the same increase in WPI and egg albumen concentration in batter formulation resulted in decrease in coating pick-up. Gluten is more effective for viscosity build up. Therefore, adequate viscosity for batters to coat foods was lost when corn and wheat flour mixture was replaced partly with WPI or egg albumen. Increasing the protein concentration decreased the pick-up further in the case of WPI and egg albumen.

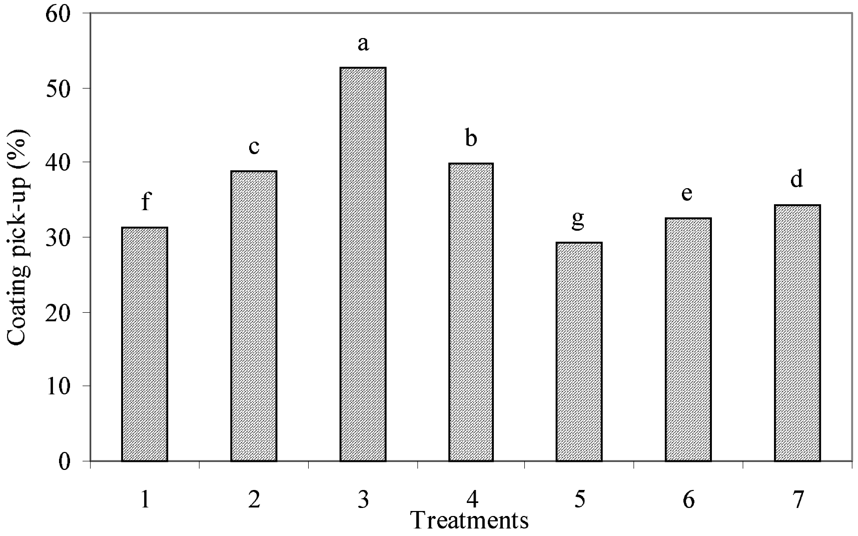

Figure 3.20 Effects of protein types on coating pick-up of deep-fat fried chicken nuggets during frying.
(1) 3% WPI, (2) 1% WPI, (3) 3% SPI, (4) 1% SPI, (5) 3% egg albumen, (6) 1% egg albumen, (7) control 2

3.2.3. Texture

The effects of protein types with different concentrations on texture of deep-fat fried chicken nuggets can be examined in terms of hardness and fracturability in Figure 3.21 and 3.22, respectively. In general, both hardness and fracturability increased with increasing frying time.

Initial moisture content was found to be inversely related with force required to break the matrix (Schiffman, 1993). Thus, the differences in water binding capacities of batters resulted in different texture values during frying. According to that, soy protein isolate (3%) added batter was found to be the least crisp coating during the initial frying period with respect to control and other ingredients (Figure 3.21). However, after 12 minutes of frying, due to its film forming ability, it was one of the formulation giving the highest hardness value. Heat-induced cross-linking in the SPI film structure contributed to the increase in toughness and decrease in flexibility (Rayner et al., 2000).

WPI addition at both concentrations resulted in crispier products (Figure 3.22). The potential formation of intermolecular disulfide crosslinks in whey protein films can improve both the barrier and mechanical properties of the films (McHugh and Krochta, 1994).

When the whole frying period was considered in statistical analysis, the addition of WPI at 3% into batter formulations had increased the hardness of fried nuggets significantly as compared to control (Table C.12). Similarly, batters with WPI (both at 1% and 3% concentration) had significant effects on fracturability of fried nuggets (Table C.13).

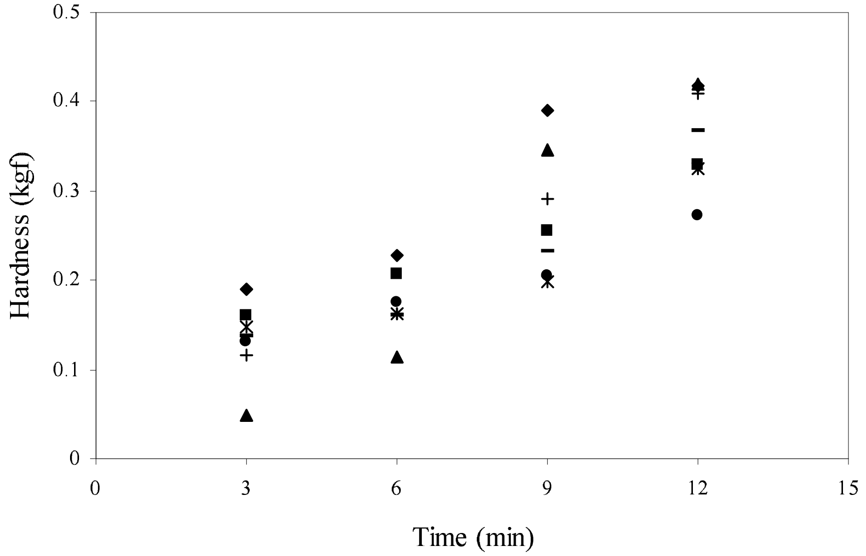

Figure 3.21 Effects of protein types on hardness of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)^{a}, (■) WPI (1%)^{ab}, (▲) SPI (3%)^{ab}, (+) SPI (1%)^{ab}, (●) egg albumen (3%)^{b}, (*) egg albumen(1%)^{b}, (-) control 2^{b}.

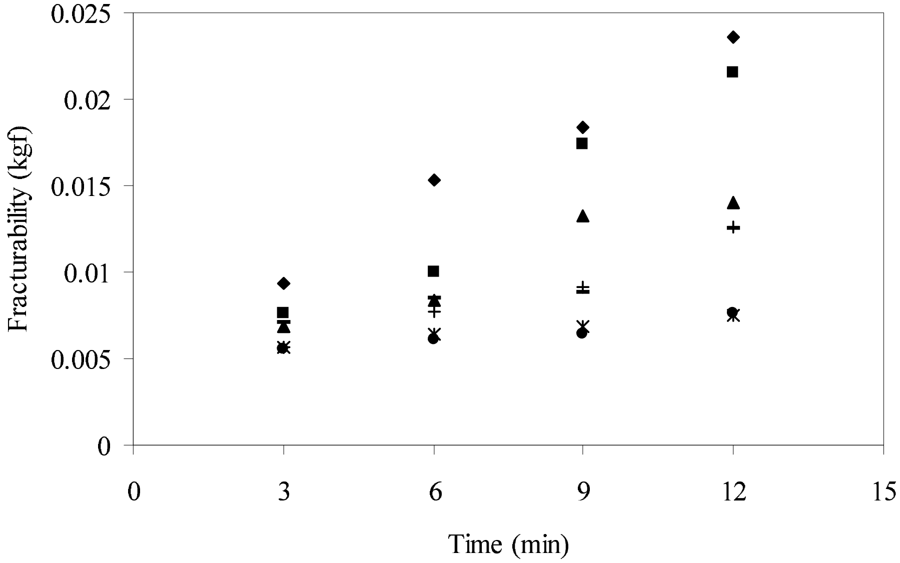

Figure 3.22 Effects of protein types on fracturability of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)[a], (■) WPI (1%)[ab], (▲) SPI (3%)[bc], (+) SPI (1%)[dc], (●) egg albumen (3%)[d], (*) egg albumen (1%)[d], (-) control 2[dc].

3.2.4. Moisture Content

The effect of protein types on moisture content of deep-fat fried chicken nuggets is given in Figure 3.23. As can be seen from this figure, protein addition to the batter formulation retained more moisture within the fried product. From the improved moisture retention, proteins can be said to be effective on reducing water vapor migration. Proteins can hold water and possess emulsifying ability due to their hydrophilic and lipophilic side chains (Mohamed et al., 1998).

At the initial stages of frying, the most effective treatment in terms of moisture retention during frying was the addition of egg albumen at 3%. Control batter lost the highest amount of water during frying. When the whole frying period was considered, the addition of egg albumen into batter formulations increased moisture retention significantly as compared to control (Table C.14). This may be due to the more hydrophobic nature of egg albumen. High moisture content obtained in the case of egg albumen formulation may be related with its porosity.

3% whey protein isolate added batters gave the highest moisture retention value after 12 minutes of frying which can be considered as optimum frying time for an acceptable product. As discussed in section 3.2.3, the potential formation of intermolecular disulfide crosslinks in whey protein films might have improved the barrier properties of the WPI film for water vapor (McHugh and Krochta, 1994). Furthermore, the hydrophobic pockets in both β–lactoglobulin and bovine serum albumin offer the potential binding of flavor, aroma and lipid compounds (McHugh and Krochta, 1994).Therefore, resistance of WPI added coating to water vapor transmission might have increased.

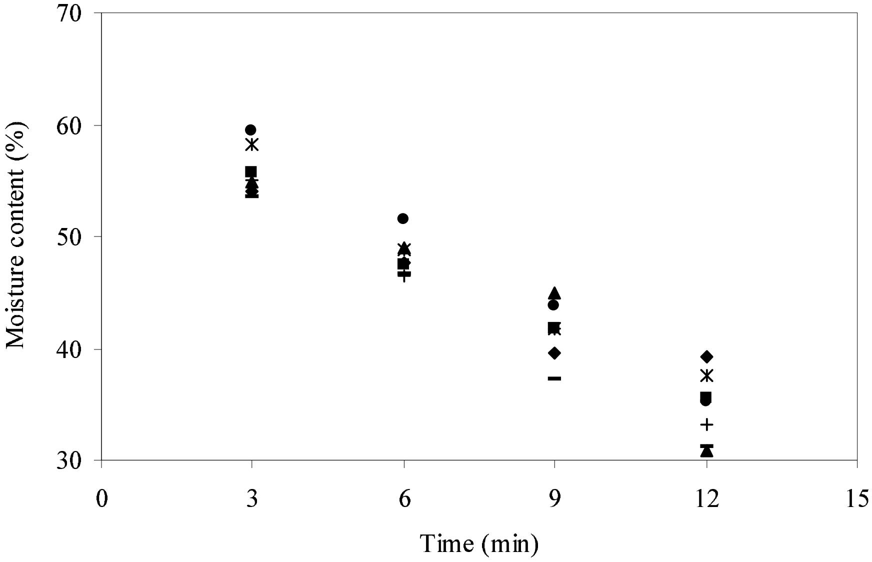

Figure 3.23 Effects of protein types on moisture content of deep-fat fried chicken nuggets during frying.

(♦) WPI (3%)^{ab}, (■) WPI (1%)^{ab}, (▲) SPI (3%)^{ab}, (+) SPI (1%)^{ab}, (●) egg albumen (3%)^{a}, (*) egg albumen (1%)^{a}, (-) control 2^{b}.

3.2.5. Oil Content

Figure 3.24 shows the effects of protein types on oil content of deep-fat fried chicken nuggets. Oil content increased during frying. Addition of different proteins at different concentrations to the batter formulation decreased oil content of the final product. Less oil absorption may be related with reduced water vapor permeability due to the formation of covalent links within films during heating (Rayner et al., 2000). Reduced oil uptake was also related with thermal gelation and the film-forming ability of proteins.

Oil content was found to be related with moisture content as in the case of flour added formulations and correlation coefficient was determined to be 0.89. Previously, a linear relationship between oil uptake and water removal has been reported (Gamble et al., 1987). WPI (3%) and egg albumen (1%) added batters provided the least oily products based on the inverse relation between oil and moisture content. Improved water vapor barrier properties of WPI added batter due to intermolecular disulfide crosslinks caused reduction in oil absorption into the product. According to Baker and Scott-Kline (1988), a batter with a high protein content produces a more nutritious coating (nutrition-conscious consumers feel that high-carbohydrate coatings contribute to obesity); egg albumen batters resulted in a lower calorie content than batters based purely on flour. Ovalbumin, the main protein in egg albumen, was also reported to reduce oil-uptake of the fried product, probably due to its lipophobic nature (Kato and Nakai, 1980).

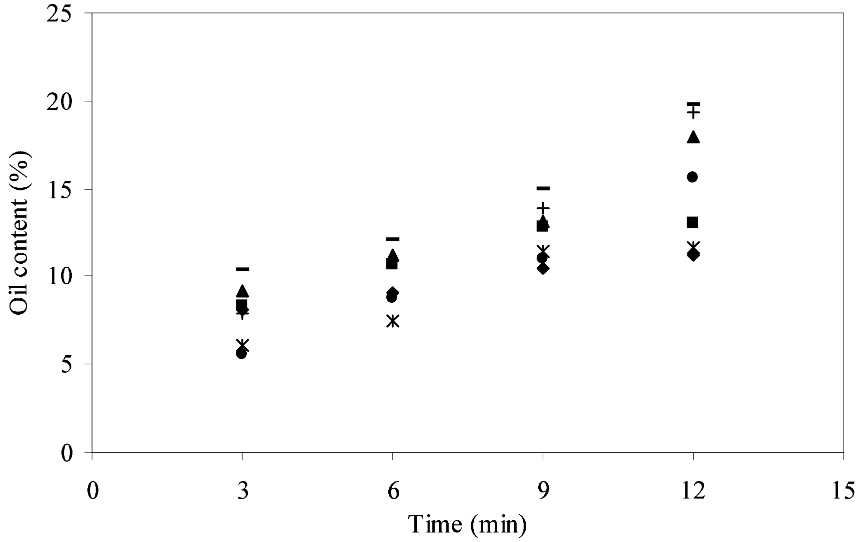

Figure 3.24 Effects of protein types on oil content of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)^{c}, (■) WPI (1%)^{bc}, (▲) SPI (3%)^{ab}, (+) SPI (1%)^{ab}, (●) egg albumen (3%)^{c}, (*) egg albumen (1%)^{c}, (-) control 2^{a}.

WPI and egg albumen added batters decreased oil absorption significantly when compared with control and SPI added batters (Table C.15). Although all of the proteins decreased oil content of the final product, chicken nuggets coated with SPI added batters absorbed more oil than the batters formulated with other proteins after 12 minutes of frying. This may be due to its isoelectric point. The formation of homogeneous free standing SPI film could be achieved in the pH ranges of 1-3 and 6-12. The film did not form between pH 4 and 5, but rather coagulated around its isoelectric point (pH = 4.5). When moving away from the isoelectric point, the SPI proteins denature, unfold and solubilize exposing sulfhydryl and hydrophobic groups. These groups associate during drying creating hydrophobic and disulfide bonding forces which form a film structure (Rayner et al., 2000). Water retention of soy protein gels is at minimum at pH 4.5 and increases rapidly as pH is increased or decreased from this region (Aoki, 1965).

The pH of 1% SPI added batter was 6.30 and that of 3% added batter was 6.50. Both pH values were not so far from the isoelectric point, which might be the reason for the low water retention and in turn high oil absorption values of SPI added batters.

3.2.6. Bulk Volume

Batters with 3% SPI was significantly effective on increasing the bulk volume of the fried nuggets when compared with control batter and other formulations (Figure 3.25 and Table C.16). This can also be seen from the images given in Appendix D. 3% SPI added batters provided the highest volume whereas 3% WPI or 3% egg albumen added batters gave the lowest volume to the deep-fat fried chicken nuggets. This can be explained by the difference between film forming abilities, water binding properties and gas holding capabilities of different proteins. High batter pick-up in the case of SPI added formulations improved film forming and gas holding abilities and so the bulk volume of nuggets. Low pick-up values observed in 3% WPI and egg albumen may be the reason for their low volume (Table C.11 and C.16). Low volume of nuggets prepared using 3% WPI containing batter is expected due to their hard texture since volume and texture are known to be inversely correlated.

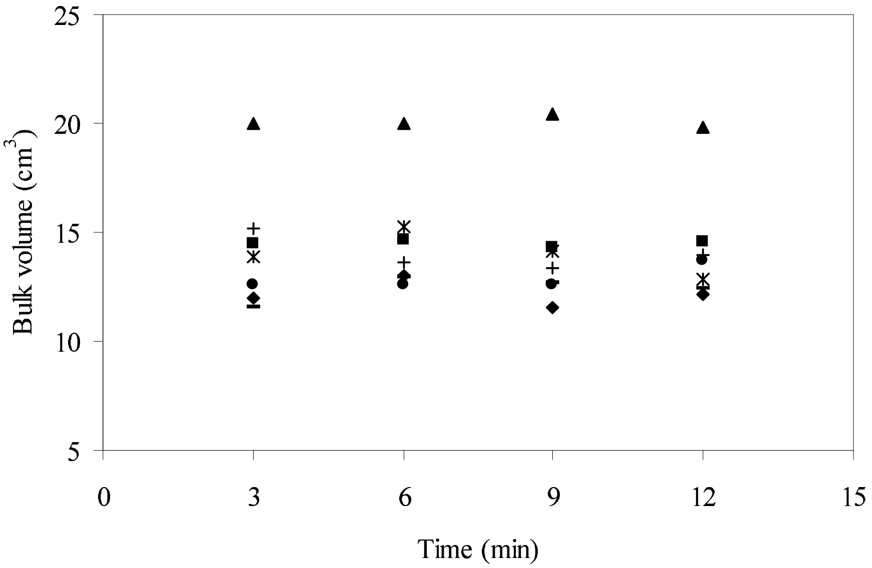

Figure 3.25 Effects of protein types on bulk volume of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)^c, (■) WPI (1%)^b, (▲) SPI (3%)^a, (+) SPI (1%)^b, (●) egg albumen (3%)^c, (*) egg albumen (1%)^b, (-) control 2^c.

3.2.7. Porosity

The development of porosity in foods, in general, depends on the initial moisture content and the composition of the material. Related with particle density of the fried nuggets, the effect of protein addition to the batter formulations on porosity of the samples can be seen from Figure 3.26. Considering the nuggets fried for 12 minutes, 3% SPI added batters gave the most porous product, whereas 3% WPI the least porous one as expected, since 3 % WPI added batters were not viscous enough to keep the gas within the system.

When all of the frying times were considered, porosity values of protein added batters were not significantly different from each other (Table C.17). The same porosity trend observed in flour types was also valid for the proteins. The initial increase and then decrease in porosity was explained by oil intrusion into pores, voids, and capillaries initially filled by air or steam generated from evaporated water (Pinthus et al., 1995b). However, for the egg albumen, 12 minutes frying was not enough for the porosity to complete its whole period, in other words porosity did not have enough time to decrease after the initial increase. For the egg albumen, the pores may not be fully filled by oil as porosity did not decrease. This also explains the high moisture content and low oil content of deep-fat fried chicken nuggets coated by egg albumen added batters.

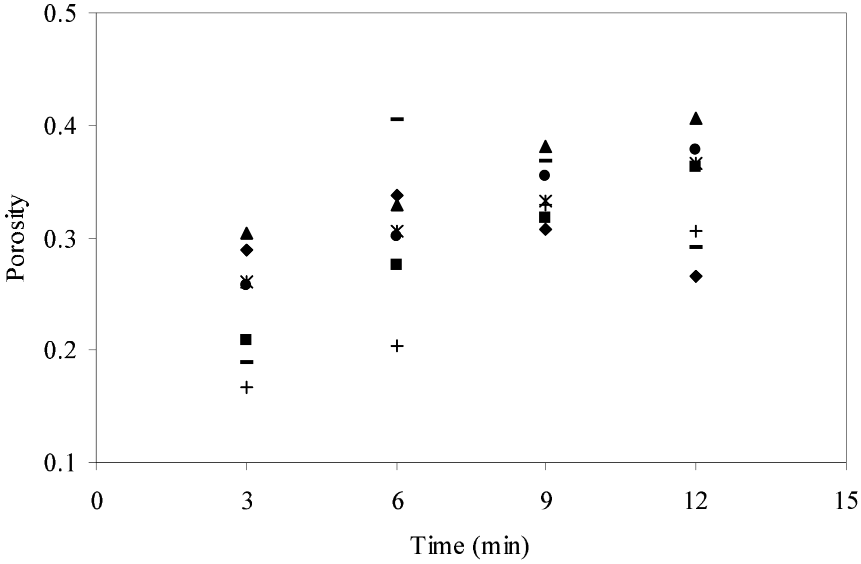

Figure 3.26 Effects of protein types on porosity of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)^{ab}, (■) WPI (1%)^{ab}, (▲) SPI (3%)^{a}, (+) SPI (1%)^{b}, (●) egg albumen (3%)^{ab}, (*) egg albumen (1%)^{ab}, (-) control 2^{ab}.

3.2.8. Cooking Yield

Percent cooking yield is an indication of adhesion during frying. The importance of improved adhesion in batters is considered mostly in terms of economic feasibility.

All types of proteins were effective in improving cooking yield except WPI (Table C.18). Batters with SPI at both 1% and 3% concentrations increased percent cooking yield significantly, whereas 3% WPI added batters gave the lowest cooking yield value (Table C.18). The effectiveness of SPI can be explained by its film forming ability.

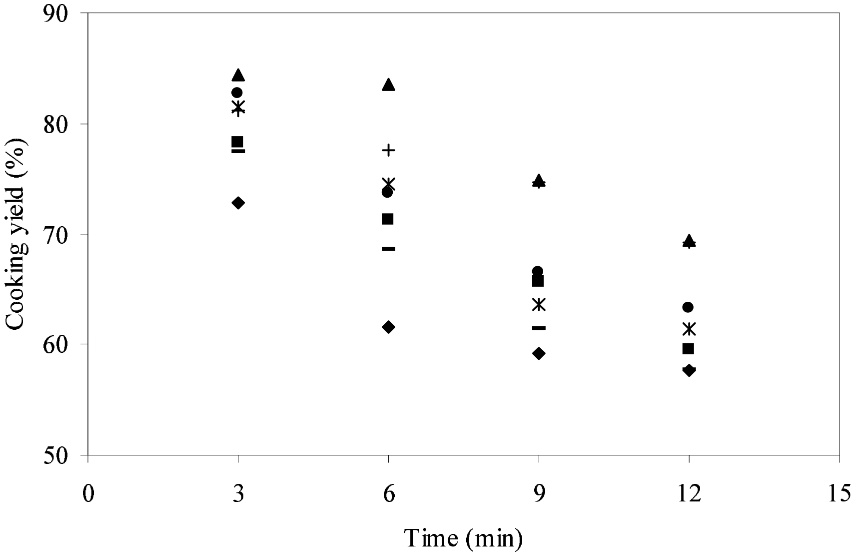

Figure 3.27 Effects of protein types on cooking yield of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%)^{d}, (■) WPI (1%)^{bc}, (▲) SPI (3%)^{a}, (+) SPI (1%)^{a}, (●) egg albumen (3%)^{b}, (*) egg albumen (1%)^{b}, (-) control 2^{c}.

3.2.9. Color

The effect of protein types on color development of deep-fat fried chicken nuggets was shown in terms of Hunter *L*, *a* and *b* values (Figure 3.28-30). As frying time increased, *L* value decreased and *a* value increased, but there was no significant trend in change in *b* value. In general, proteins increased browning of the fried batter because more amine groups were present to participate in the Maillard reaction (Mohamed et al, 1998). However, some proteins like egg albumen (3%) and soy protein (3%) had lighter crust colors with respect to control and other coatings (Figure 3.28 and Table C.19). It was also reported that a high proportion of egg albumen in batter formulations for coating chicken nuggets caused problems in color (Fizsman and Salvador, 2003). The amount of reducing sugars and amino acids has been shown to have an effect on the color of fried potatoes (Habib and Brown, 1956; Schallenberger, et al., 1959). In addition, the amount of oil absorbed by the product during frying was also effective on the color of deep-fat fried chicken nuggets. Therefore, the darker color of the control as compared to high concentrations of egg albumen and SPI might be due to its high oil content (Figure 3.24 and 3.28). 3% WPI added batters were significantly effective on color formation of deep-fat fried chicken nuggets giving the darkest color in terms of lightness (*L*) and redness (*a*) (Table C.19-20). This may be related with its low bulk volume (Table C.16).

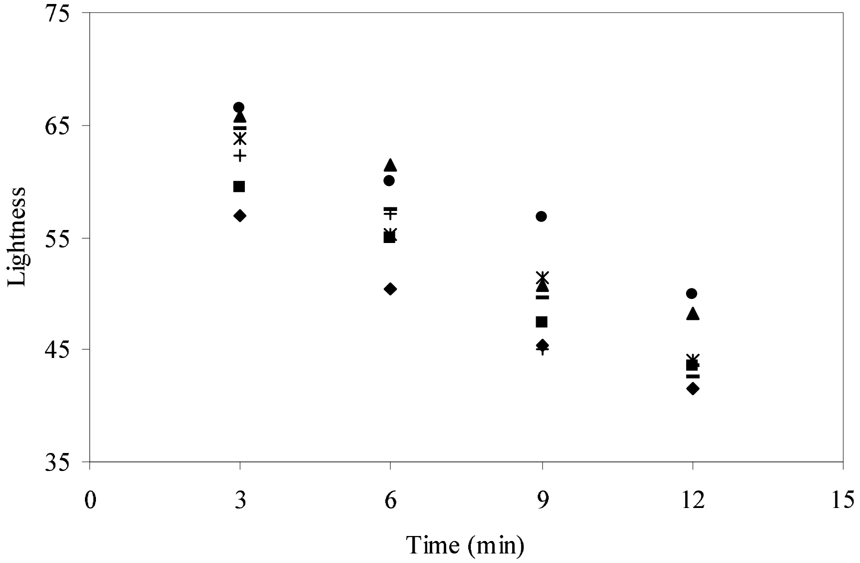

Figure 3.28 Effects of protein types on lightness of deep-fat fried chicken nuggets during frying.

(♦) WPI (3%)^{c}, (■) WPI (1%)^{b}, (▲) SPI (3%)^{a}, (+) SPI (1%)^{b}, (●) egg albumen (3%)^{a}, (*) egg albumen (1%)^{b}, (-) control 2^{b}.

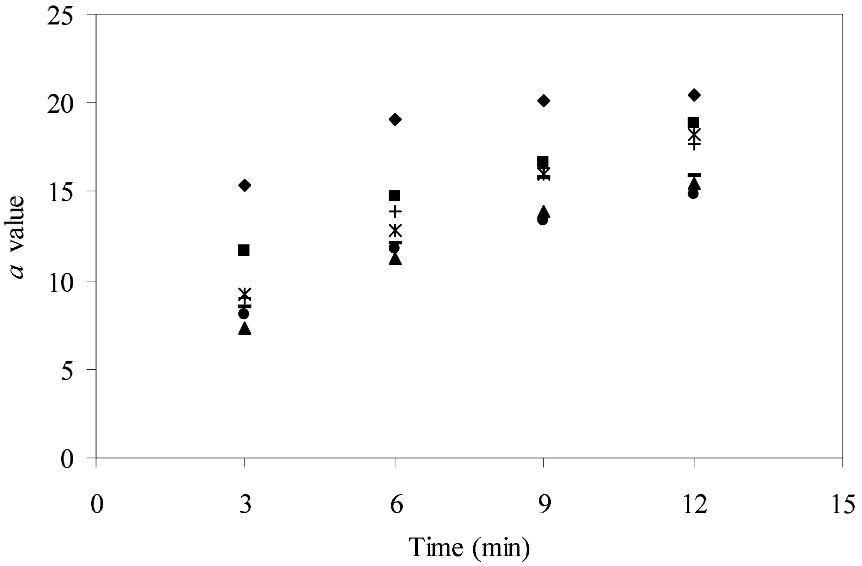

Figure 3.29 Effects of protein types on Hunter *a* value of deep-fat fried chicken nuggets during frying.

(♦) WPI (3%)[a], (■) WPI (1%)[b], (▲) SPI (3%)[e], (+) SPI (1%)[c], (●) egg albumen (3%)[e], (*) egg albumen (1%)[cd], (-) control 2[de].

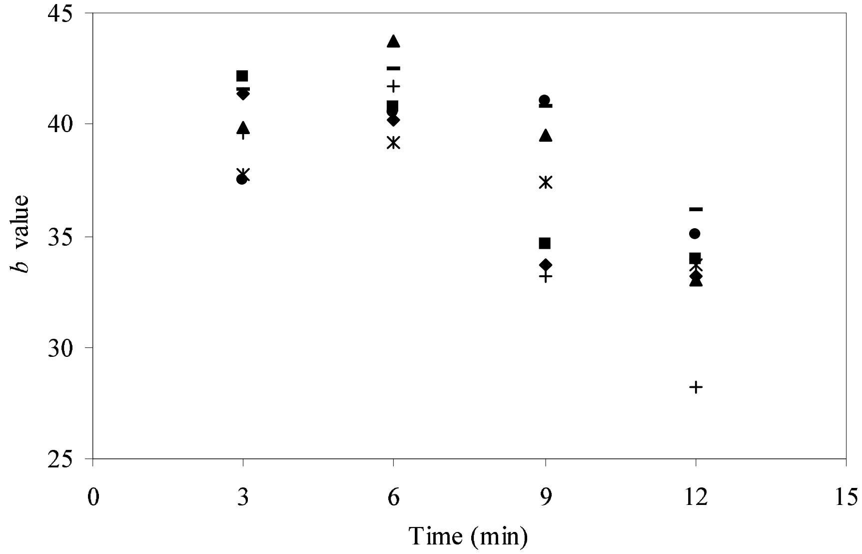

Figure 3.30 Effects of protein types on Hunter *b* value of deep-fat fried chicken nuggets during frying.
(♦) WPI (3%), (■) WPI (1%), (▲) SPI (3%), (+) SPI (1%), (●) egg albumen (3%), (*) egg albumen (1%), (-) control 2.

3.3. Comparison of the Effects of Flour and Protein Types on Deep-Fat Fried Chicken Nuggets

As the final part of the study, the effects of flour and protein types were compared in terms of several important quality attributes. The flours and proteins to be compared were chosen with respect to their ability to minimize the amount of oil absorbed by deep-fat fried chicken nuggets. Therefore, deep-fat fried chicken nuggets coated with soy flour, rice flour, 3% WPI, 1%WPI and 1% egg albumen added batters were compared at 12 minutes of frying, which was found to be the optimum frying time to produce an acceptable product.

Oil content is a very important quality parameter for deep-fat fried products. Batter formulations with different flours provided the fried chicken nuggets with lower oil content when compared with proteins, but not significantly different from 3% WPI added batters (Fig. 3.31 and Table C.21).

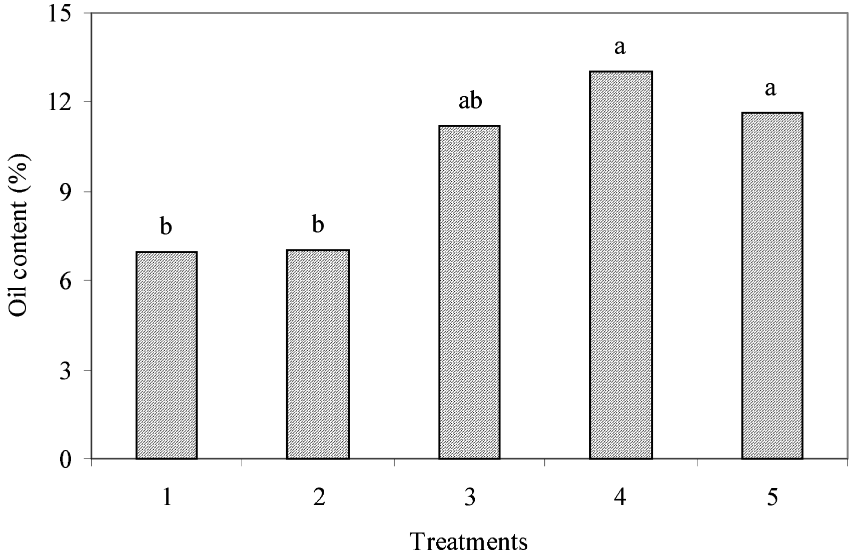

Figure 3.31 The effect of different types of flours and proteins in batter formulations on oil content of deep-fat fried chicken nuggets
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI, (5) 1% egg albumen

One of the most important quality parameters for deep-fat fried products was texture in terms of hardness and fracturability. Proteins were found to provide harder texture to the batters that could not be obtained with soy and rice flours (Fig. 3.32). When fracturability of both flour and protein formulations were compared, WPI (1, 3%) added batters were found to give the crunchiest products (Fig. 3.32) due to the potential formation of intermolecular disulfide crosslinks (McHugh and Krochta, 1994). In statistical analysis, the addition of WPI at 3%

into batter formulations increased the hardness of fried nuggets significantly as compared to flours (Table C.22). Similarly, batters with WPI (1% and 3%) had significant effects on fracturability of fried nuggets (Table C.23). Egg albumen (1%) and rice flour, on the other hand, could not provide enough fracturability, which is a good indicator of crispiness.

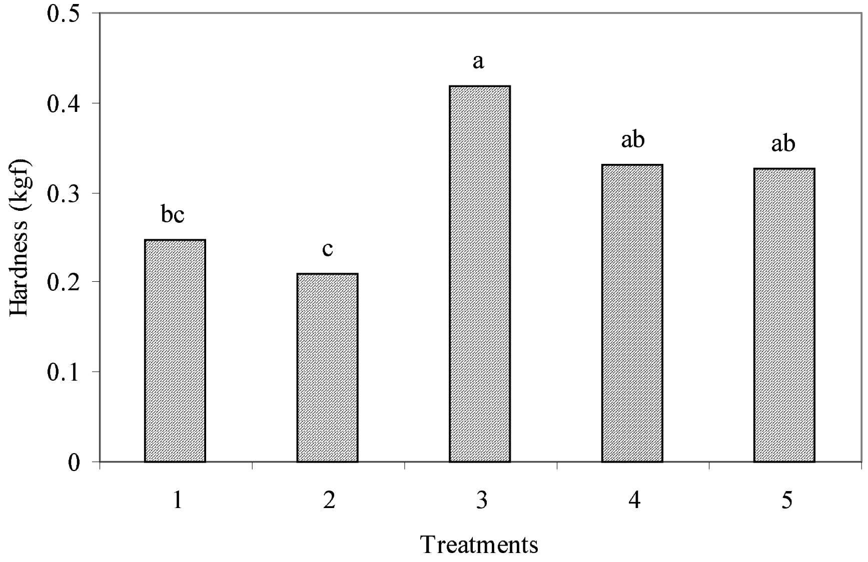

Figure 3.32 The effect of different types of flours and proteins in batter formulations on hardness of deep-fat fried chicken nuggets
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI , (5) 1% egg albumen

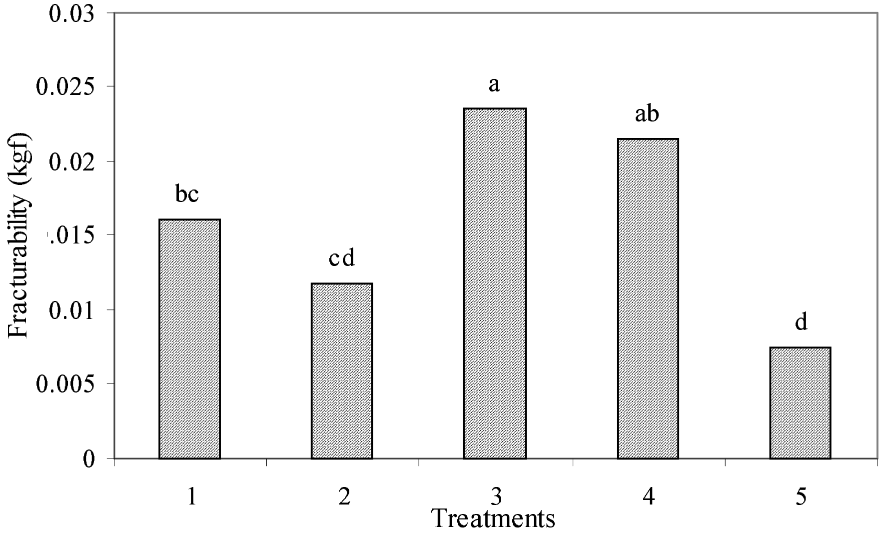

Figure 3.33 The effect of different types of flours and proteins in batter formulations on fracturability of deep-fat fried chicken nuggets
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI , (5) 1% egg albumen

Soy flour addition to the batter formulation was found to have the most significant effect on cooking yield as can be seen in Figure 3.34 and Table C.24 related with its high water binding capacity (Table A.1). The retention of higher moisture levels in the fried product and the reduction of product shrinkage is known to increase cooking yield (Duxburry, 1989).

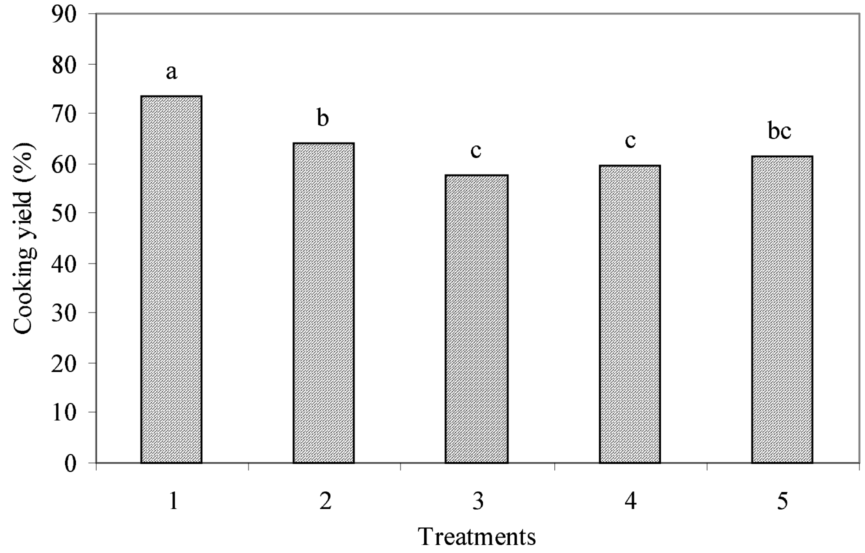

Figure 3.34 The effect of different types of flours and proteins in batter formulations on cooking yield of deep-fat fried chicken nuggets.
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI, (5) 1% egg albumen

When the effects of batter ingredients on color of deep-fat fried chicken nuggets were compared at 12 minutes of frying, 3% WPI added batters were significantly effective on color development of deep-fat fried chicken nuggets giving the darkest color in terms of lightness (*L*) and redness (*a*) (Figure 3.35-3.36 and Table C.25-26). Generally, proteins caused increased browning to the fried batter, due to more amine groups present to participate in the Maillard reaction.

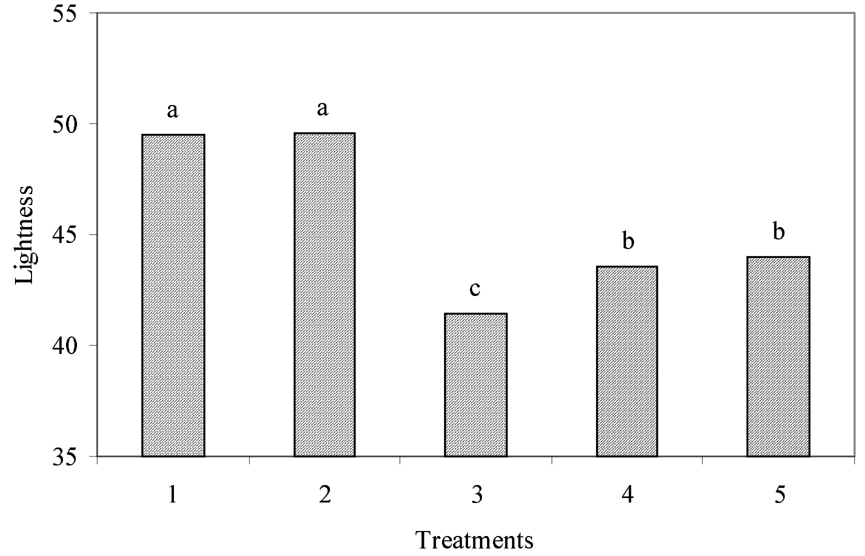

Figure 3.35 The effect of different types of flours and proteins in batter formulations on lightness value of deep-fat fried chicken nuggets.
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI, (5) 1% egg albumen

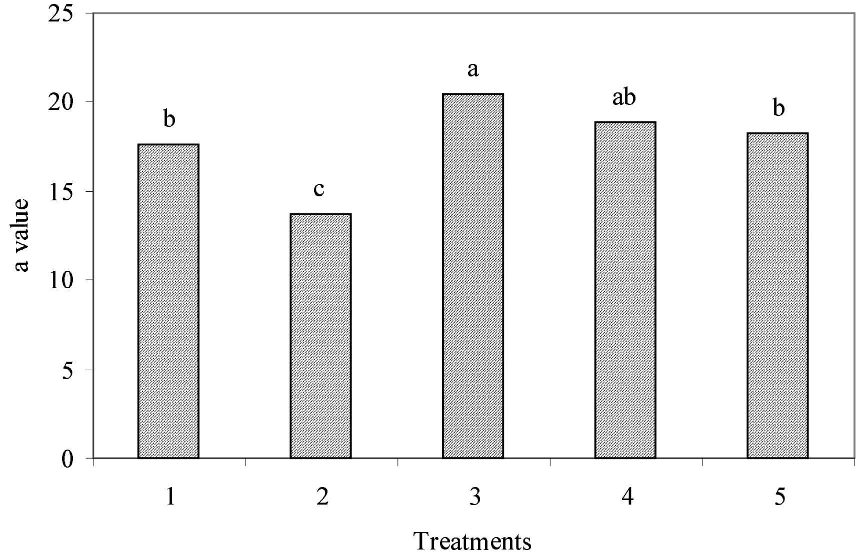

Figure 3.36 The effect of different types of flours and proteins in batter formulations on *a* value of deep-fat fried chicken nuggets.
(1) soy flour, (2) rice flour, (3) 3% WPI, (4) 1% WPI, (5) 1% egg albumen

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Addition of different flour and protein types into batter formulations was found to affect both batter rheology and quality attributes of deep-fat fried chicken nuggets. When the flow behavior of batters were examined, all batters were found to be non-Newtonian. All batters could be modeled as power-law fluid and had shear-thinning behavior except egg albumen added batters. For the time dependency, all batter types were found to have thixotropic behavior. Soy flour and soy protein isolate were found to provide the highest apparent viscosity to the batters. Batter viscosity was correlated with coating pick-up. Hardness, fracturability and oil content increased, whereas moisture content and cooking yield decreased with respect to frying time.

Soy flour was found to be an effective ingredient on improving quality parameters in terms of increased coating pick-up, cooking yield and darker color. Both soy flour and rice flour provided reduced oil absorption as compared to control.

Addition of different proteins to batter formulations was found to be significantly effective on quality attributes of deep-fat fried chicken nuggets. WPI and egg albumen added batters reduced oil absorption significantly. Control batter formulation was found to provide the highest oil content. 3% WPI added batters were significantly effective on color and texture improvement of deep-fat fried chicken nuggets. Soy protein isolate added batters provided the highest coating pick-up and cooking yield among the others.

When the effects of flour and protein types were considered at 12 minutes of frying, which was considered as the optimum frying time to produce acceptable product, 3% WPI was found to be the most effective ingredient on improving quality parameters of deep-fat fried chicken nuggets as compared to the other formulations used in this study. 3% WPI added batters provided the hardest and crunchiest product with the darkest color. It also reduced the oil content of fried nuggets in a considerable amount. On the other hand, batters with 3% WPI had low cooking yield values. Therefore, if high cooking yield with low oil content is desired, soy flour can be advised to be used in batter formulations for chicken nuggets.

Further research may be done to determine the effects of different ingredients like other flour types (barley, chickpea, etc.), emulsifiers or flavorings, combination of starches and proteins, etc., and their concentrations on quality parameters of deep-fat fried products. Different frying methods like microwave frying can be studied. In addition, the effects of different breadings can be investigated. Suitable batter formulations for the process of thawing can also be improved.

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APPENDIX A

WATER BINDING CAPACITY

Table A.1 Water binding capacities (WBC) of different flours and proteins

	WBC (w/w)
Soy flour	2.72
Rice flour	1.4
Corn flour	0.92
Corn flour + wheat flour	1.04
Whey protein isolate	0.04
Soy protein isolate	5.36
Egg albumen	0.12
Gluten	1.32

APPENDIX B

TEXTURE PROFILE ANALYSIS

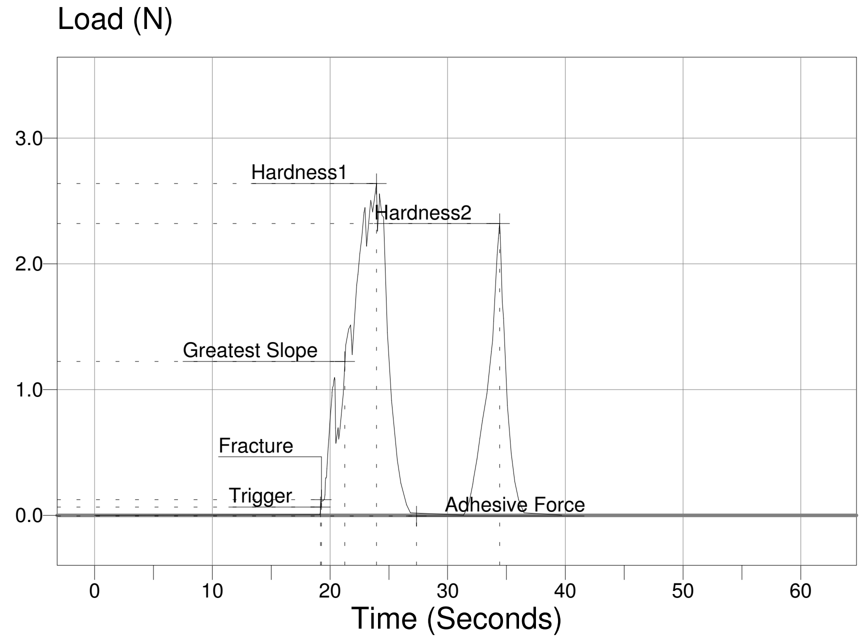

Figure B.1 Typical TPA curve for chicken nugget.

APPENDIX C

ANOVA and DUNCAN TABLES

Table C.1 ANOVA and Duncan's Multiple Range Test Table for coating pick-up of fried samples with different flour types during frying

Class	Levels	Values
Formulations	3	control 1, soy flour, rice flour

Number of observations in data set = 32

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	2	1019.01107	509.50554	1382.30	0.0001
Error	29	10.66600	0.36779		
Total	31	1029.67707			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	2	1923.79275	509.50554	1382.30	0.0001

Alpha = 0.05

Means with the same letter are not significantly different.

Duncan Grouping	**Mean**	**N**	**Formulations**
A	48.033	11	soy flour
B	42.853	12	control 1
C	33.766	9	rice flour

Table C.2 ANOVA and Duncan's Multiple Range Test Table for hardness of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	0.01834624	0.003669248	7.44	0.0001
Error	6	0.00295713	0.000492855		
Total	11	0.02130338			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	0.00218481	0.001092405	2.22	0.1902
Frying time	3	0.01616143	0.005387143	10.93	0.0076

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	0.19848	4	control 1
A	0.17224	4	soy flour
A	0.16795	4	rice flour

Table C.3 ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	0.00009809	0.0000196180	33.33	0.0003
Error	6	0.00000353	0.0000005883		
Total	11	0.00010163			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	0.00002608	0.000013040	22.15	0.0017
Frying time	3	0.00007201	0.000024003	40.78	0.0002

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	0.0117439	4	soy flour
B	0.0092671	4	control 1
B	0.0082298	4	rice flour

Table C.4 ANOVA and Duncan's Multiple Range Test Table for moisture content of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	226.948167	45.38963344	31.47	0.0003
Error	6	8.65483835	1.442473058		
Total	11	235.603005			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	8.19118605	4.095593025	2.84	0.1356
Frying time	3	218.756981	72.91899373	50.55	0.0001

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	48.2414	4	soy flour
A	47.5852	4	rice flour
A	46.2553	4	control 1

Table C.5 ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	30.4823025	6.096460502	20.82	0.0010
Error	6	1.75732639	0.292887732		
Total	11	32.2396289			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	14.01252188	7.00626094	23.92	0.0014
Frying time	3	16.46978063	5.48992688	18.74	0.0019

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	8.6127	4	control 1
B	6.3924	4	rice flour
B	6.2545	4	soy flour

Table C.6 ANOVA and Duncan's Multiple Range Test Table for bulk volume of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	5.15888250	1.0317765	0.55	0.7354
Error	6	11.24405647	1.874009412		
Total	11	16.40293898			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	0.38115636	0.19057818	0.10	0.9048
Frying time	3	4.77772614	1.59257538	0.85	0.5154

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	18.0484	4	control 1
A	17.9448	4	soy flour
A	17.6294	4	rice flour

Table C.7 ANOVA and Duncan's Multiple Range Test Table for porosity of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	0.02195793	0.004391586	9.80	0.0075
Error	6	0.00268981	0.0004483017		
Total	11	0.02464774			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	0,00002012	0.00001006	0.02	0.9779
Frying time	3	0.02193781	0.007312603	16.31	0.0027

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	0.33633	4	rice flour
A	0.33541	4	soy flour
A	0.33324	4	control 1

Table C.8 ANOVA and Duncan's Multiple Range Test Table for cooking yield of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	451.74577730	90.34915546	54.29	0.0001
Error	6	9.98525066	1.664208443		
Total	11	461.73102795			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	144.16134404	72.080672	43.31	0.0003
Frying time	3	307.58443325	102.5281444	61.61	0.0001

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	79.3871	4	soy flour
B	76.2768	4	control 1
C	70.9905	4	rice flour

Table C.9 ANOVA and Duncan's Multiple Range Test Table for lightness of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	202.48809980	40.49761996	30.46	0.0003
Error	6	7.97691160	1.329485267		
Total	11	210.46501140			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	17.14154087	8.570770435	6.45	0.0320
Frying time	3	185.34655893	61.7821863	46.47	0.0002

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	55.7742	4	rice flour
A	55.1899	4	control 1
B	52.9977	4	soy flour

Table C.10 ANOVA and Duncan's Multiple Range Test Table for *a* values of fried samples with different flour types during frying

Class	Levels	Values
Flour types	3	control 1, soy flour, rice flour
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 12

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	5	83.14478798	16.6289576	69.83	0.0001
Error	6	1.42879063	0.2381317717		
Total	11	84.57357860			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Flour Type	2	28.56442911	14.28221456	59.98	0.0001
Frying time	3	54.58035887	18.19345296	76.40	0.0001

Duncan Grouping	**Mean**	**N**	**Flour Type**
A	14.5033	4	soy flour
B	11.7642	4	control 1
C	10.8788	4	rice flour

Table C.11 ANOVA and Duncan's Multiple Range Test Table for coating pick-up of fried samples with different protein types during frying

Class	Levels	Values
Formulations	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2

Number of observations in data set = 93

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	6	4785.70998796	797.6183312	1052.71	0.0001
Error	86	65.16045849	0.7576797499		
Total	92	4850.87044645			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	6	4785.70998796	797.6183312	1052.71	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	52.6109	12	3% SPI
B	39.8792	9	1% SPI
C	38.7919	11	1% WPI
D	34.3961	21	control 2
E	32.4061	7	1% egg albumen
F	31.2974	16	3% WPI
G	29.3206	17	3% egg albumen

Table C.12 ANOVA and Duncan's Multiple Range Test Table for hardness of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	0.25701126	0.0285568067	12.86	0.0001
Error	18	0.03996311	0.0022201728		
Total	27	0.29697437			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	0.03067819	0.0051130317	2.30	0.0795
Frying time	3	0.22633307	0.0754443567	33.98	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	0.30701	4	3% WPI
AB	0.24482	4	1% SPI
AB	0.23788	4	1% WPI
AB	0.23208	4	3% SPI
B	0.22407	4	control 2
B	0.20869	4	1% egg albumen
B	0.19547	4	3% egg albumen

Table C.13 ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	0.00056202	0.0000624467	11.06	0.0001
Error	18	0.00010162	0.0000056456		
Total	27	0.00066365			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	0.00034892	0.000058153	10.30	0.0001
Frying time	3	0.00021310	0.000071033	12.58	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	0.016647	4	3% WPI
AB	0.014109	4	1% WPI
BC	0.010635	4	3% SPI
CD	0.009224	4	control 2
CD	0.008772	4	1% SPI
D	0.006601	4	1% egg albumen
D	0.006407	4	3% egg albumen

Table C.14 ANOVA and Duncan's Multiple Range Test Table for moisture content of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	1794.32626326	199.3695848	48.19	0.0001
Error	18	74.46413711	4.136896506		
Total	27	1868.79040037			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	70.97800487	11.82966748	2.86	0.0795
Frying time	3	1723.34825838	574.4494193	138.86	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	47.492	4	3% egg albumen
A	46.618	4	1% egg albumen
AB	45.111	4	3% WPI
AB	45.072	4	1% WPI
AB	44.894	4	3% SPI
AB	44.193	4	1% SPI
B	42.139	4	control 2

Table C.15 ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	310.32452239	34.48050248	16.67	0.0001
Error	18	37.22999793	2.068333218		
Total	27	347.55452032			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	88.32389220	14.7206487	7.12	0.0005
Frying time	3	222.00063019	74.00021003	35.78	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	14.264	4	control 2
AB	13.017	4	1% SPI
AB	12.882	4	3% SPI
BC	11.219	4	1% WPI
C	10.223	4	3% egg albumen
C	9.718	4	3% WPI
C	9.188	4	1% egg albumen

Table C.16 ANOVA and Duncan's Multiple Range Test Table for bulk volume of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	175.61568380	19.51285376	45.35	0.0001
Error	18	7.74506981	0.4302816561		
Total	27	183.36075361			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	174.89054376	29.14842395	67.74	0.0001
Frying time	3	0.72514004	0.2417133467	0.56	0.6471

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	20.0669	4	3% SPI
B	14.4971	4	1% WPI
B	14.0455	4	1% egg albumen
B	14.0000	4	1% SPI
C	12.8488	4	3% egg albumen
C	12.3951	4	control 2
C	12.1696	4	3% WPI

Table C.17 ANOVA and Duncan's Multiple Range Test Table for porosity of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	0.07207213	0.0080080144	4.09	0.0053
Error	18	0.03520399	0.0019557772		
Total	27	0.10727612			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	0.02436601	0.0040610017	2.08	0.1073
Frying time	3	0.04770612	0.01590204	8.13	0.0012

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	0.35552	4	3% SPI
AB	0.32223	4	3% egg albumen
AB	0.31604	4	1% egg albumen
AB	0.31358	4	control 2
AB	0.29997	4	3% WPI
AB	0.29124	4	1% WPI
B	0.25148	4	1 % SPI

Table C.18 ANOVA and Duncan's Multiple Range Test Table for cooking yield of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	1843.38579641	204.820644	39.31	0.0001
Error	18	93.79865402	5.211036334		
Total	27	1937.18445043			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	662.42444441	110.4040741	21.19	0.0001
Frying time	3	1180.96135200	393.653784	75.54	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	78.035	4	3% SPI
A	75.679	4	1% SPI
B	71.556	4	3% egg albumen
B	70.264	4	1% egg albumen
BC	68.651	4	1% WPI
C	66.232	4	control 2
D	62.805	4	3% WPI

Table C.19 ANOVA and Duncan's Multiple Range Test Table for lightness of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	1564.84059315	173.871177	57.08	0.0001
Error	18	54.82931047	3.046072804		
Total	27	1619.66990362			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	253.88659407	42.31443233	13.89	0.0001
Frying time	3	1310.95399908	436.9846663	143.46	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	58.247	4	3% egg albumen
A	56.556	4	3% SPI
B	53.603	4	1% egg albumen
B	53.526	4	control 2
B	51.985	4	1% SPI
B	51.317	4	1% WPI
C	48.540	4	3% WPI

Table C.20 ANOVA and Duncan's Multiple Range Test Table for *a* values of fried samples with different protein types during frying

Class	Levels	Values
Protein types	7	3% WPI, 1% WPI, 3% SPI, 1% SPI, 3% egg albumen, 1% egg albumen, control 2
Frying time (min)	4	3, 6, 9, 12

Number of observations in data set = 28

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	9	357.33366125	39.70374013	75.30	0.0001
Error	18	9.49087933	0.5272710739		
Total	27	366.82454058			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Protein Type	6	132.29709374	22.04951562	41.82	0.0001
Frying time	3	225.03656751	75.01218917	142.26	0.0001

Duncan Grouping	**Mean**	**N**	**Protein Type**
A	18.7358	4	3% WPI
B	15.4609	4	1% WPI
C	14.2173	4	1% SPI
CD	14.0646	4	1% egg albumen
DE	13.0830	4	control 2
E	12.0161	4	3 % egg albumen
E	11.9911	4	3% SPI

Table C.21 ANOVA and Duncan's Multiple Range Test Table for oil content of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen

Number of observations in data set = 13

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	81.98436661	20.49609165	8.39	0.0058
Error	8	19.55426743	2.444283429		
Total	12	101.53863404			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	81.98436661	20.49609165	8.39	0.0058

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	13.186	4	1% WPI
A	11.646	3	1% egg albumen
AB	10.014	2	3% WPI
B	7.029	2	rice flour
B	6.989	2	soy flour

Table C.22 ANOVA and Duncan's Multiple Range Test Table for hardness of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen.

Number of observations in data set = 14

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.06055162	0.0151379050	5.02	0.0209
Error	9	0.02711310	0.0030125667		
Total	13	0.08766471			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	0.06055162	0.015137905	5.02	0.0209

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	0.41868	2	3% WPI
AB	0.33000	3	1% WPI
AB	0.32544	3	1% egg albumen
BC	0.24726	4	soy flour
C	0.20885	2	rice flour

Table C.23 ANOVA and Duncan's Multiple Range Test Table for fracturability of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen

Number of observations in data set = 18

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	0.00070306	0.000175765	10.22	0.0006
Error	13	0.00022355	0.000017196		
Total	17	0.00092661			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	0.00070306	0.000175765	10.22	0.0006

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	0.023606	3	3% WPI
AB	0.021516	4	1% WPI
BC	0.016041	3	soy flour
CD	0.011748	3	rice flour
D	0.007524	5	1% egg albumen

Table C.24 ANOVA and Duncan's Multiple Range Test Table for yield of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen

Number of observations in data set = 23

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	847.91851398	211.9796285	39.51	0.0001
Error	18	96.57609729	5.365338738		
Total	22	944.49461127			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	847.91851398	211.9796285	39.51	0.0001

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	73.278	9	soy flour
B	64.185	6	rice flour
BC	61.413	3	1% egg albumen
C	59.544	2	1% WPI
C	57.725	3	3% WPI

Table C.25 ANOVA and Duncan's Multiple Range Test Table for lightness of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen

Number of observations in data set = 49

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	486.60441164	121.6511029	44.63	0.0001
Error	44	119.94660877	2.726059289		
Total	48	606.55102041			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4		121.6511029		

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	49.5600	10	rice flour
A	49.4909	11	soy flour
B	43.9571	7	1% egg albumen
B	43.5813	16	1% WPI
C	41.4600	5	3% WPI

Table C.26 ANOVA and Duncan's Multiple Range Test Table for *a* value of fried samples with the chosen flour and protein types during frying

Class	Levels	Values
Formulations	5	soy flour, rice flour, 3% WPI, 1% WPI, 1% egg albumen

Number of observations in data set = 49

Source	DF	Sum of Squares	Mean Square	F Value	$P_r > F$
Model	4	243.02717181	60.75679295	22.81	0.0001
Error	44	117.18956288	2.663399155		
Total	48	360.21673469			

Source	DF	Type III SS	Mean Square	F Value	$P_r > F$
Formulations	4	243.02717181	60.75679295	22.81	0.0001

Duncan Grouping	**Mean**	**N**	**Flour & Protein Type**
A	20.4200	5	3% WPI
AB	18.8556	9	1% WPI
B	18.2500	8	1% egg albumen
B	17.5714	14	soy flour
C	13.7385	13	rice flour

APPENDIX D

FIGURES OF DEEP-FAT FRIED CHICKEN NUGGETS

Figure D.1 Image of chicken nuggets coated with rice flour added batter at 3, 6, 9 and 12 minutes of frying.

Figure D.2 Image of chicken nuggets coated with soy flour added batter at 3, 6, 9 and 12 minutes of frying.

Figure D.3 Image of chicken nuggets coated with control (1) batter at 3, 6, 9 and 12 minutes of frying.

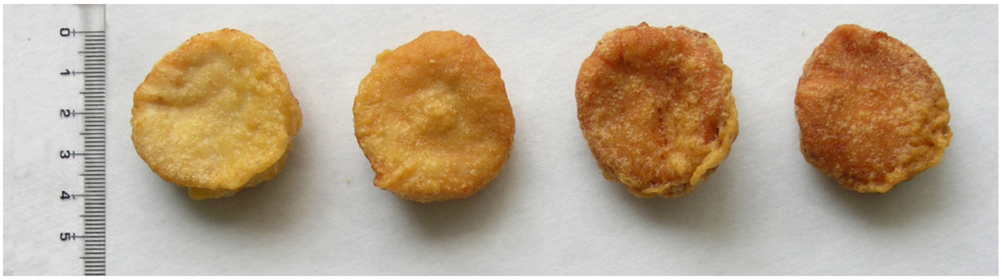

Figure D.4 Image of chicken nuggets coated with 3% WPI added batter at 3, 6, 9 and 12 minutes of frying.

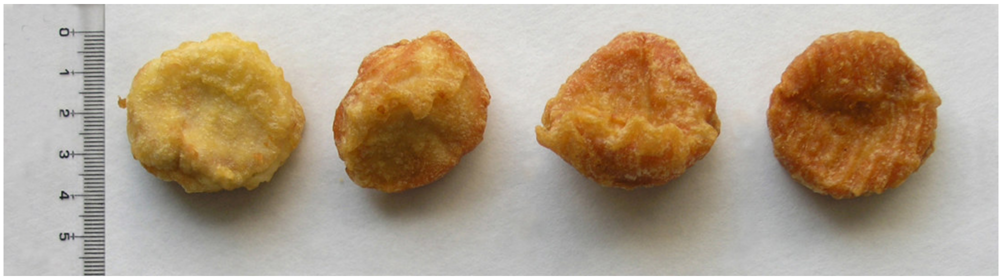

Figure D.5 Image of chicken nuggets coated with 1% WPI added batter at 3, 6, 9 and 12 minutes of frying.

Figure D.6 Image of chicken nuggets coated with 3% SPI added batter at 3, 6, 9 and 12 minutes of frying.

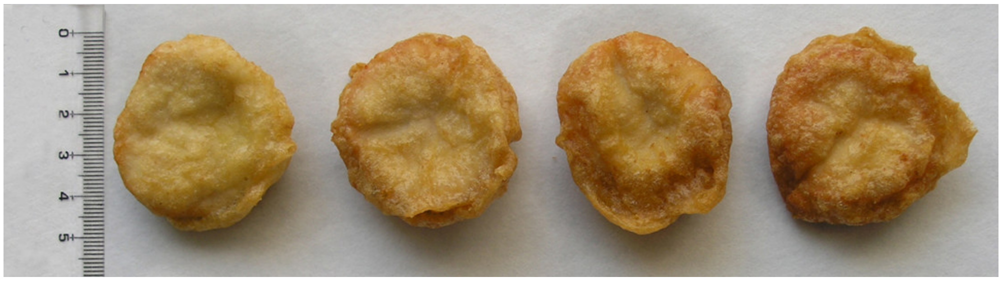

Figure D.7 Image of chicken nuggets coated with 1% SPI added batter at 3, 6, 9 and 12 minutes of frying.

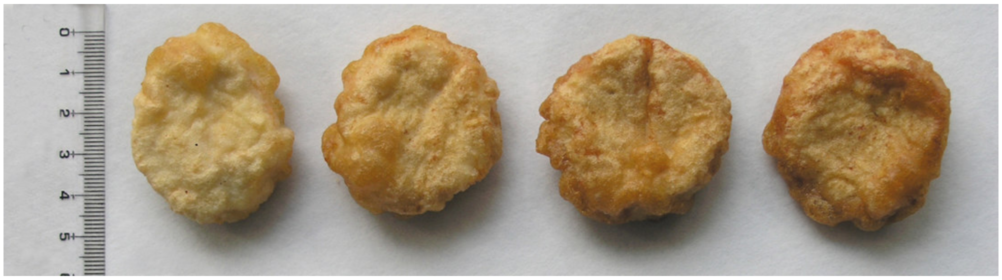

Figure D.8 Image of chicken nuggets coated with 3% egg albumen added batter at 3, 6, 9 and 12 minutes of frying.

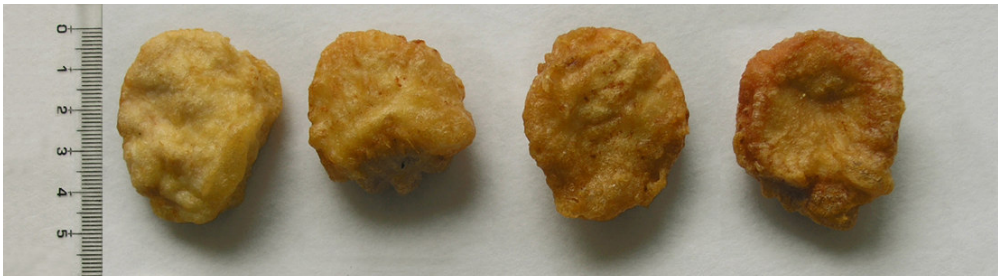

Figure D.9 Image of chicken nuggets coated with 1% egg albumen added batter at 3, 6, 9 and 12 minutes of frying.

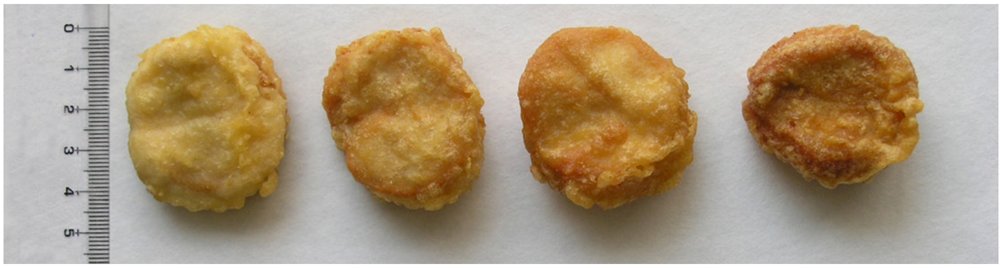

Figure D.10 Image of chicken nuggets coated with control (2) batter at 3, 6, 9 and 12 minutes of frying.